What's so Special About Philosophy?

Unraveling Wikipedia's First Link Network

Abstract

Apples, oranges, and the most obscure Dylan song too—is everything a few clicks from Philosophy? Within Wikipedia, the surprising answer is yes: nearly all paths[1] [2] *lead to Philosophy. Wikipedia is the largest, most meticulously indexed collection of human knowledge ever amassed.* [3] *More than information about a topic though, Wikipedia is a marvelous web of naturally emerging relationships. By following the First Link in an article, we connect entries to form a directed network within Wikipedia: Wikipedia's First Link Network. Here we study the English edition of Wikipedia's First Link Network for insight into how we relate topics, ideas, people, objects, and events.*

We algorithmically parse all 4.7 million articles to construct a map of Wikipedia's First Link Network. In a novel approach to uncover structure, we traverse every possible path through the network, measuring the accumulation of First Links, path lengths, basins, cycles, and even particular articles funneling links into the cycles. We discover many scale-free distributions, find Philosophy at a salient center, and uncover a flow from specific to general with basins around fundamental notions such as Community, State, and Science. Curiously, we also observe a gravitation towards topical articles including Health Care and Fossil Fuel. These findings enrich our view of how we connect and structure an ever growing load of information.

At no point in history has a larger or more meticulously indexed collection of human knowledge existed. In amassing such an awe-inspiring collection, we formed an equally impressive web. Through the efforts of millions of individuals, working independently, ((cite)) we naturally linked topics, inventions, people, objects, places, and events across space and time. The web we weaved, and continue to weave, is a wealth of information not only about those notable inventions, places, figures, and ideas, but also about *relationships* among them. We study the relationships in this naturally arising web through the hyperlinks connecting one article to another.

We build Wikipedia's First Link Network by following the First Link, not in parenthesis, inside the main body of each article in the English edition of Wikipedia. For the directed network to meaningfully reflect how we associate one article to another, we exclude links in parenthesis, disregarding pronunciation keys or disambiguations. We also exclude any links in the side-bar elements, as well as any links to external pages, files, or WikiMedia projects outside of Wikipedia (such as Wiktionary). This procedure

[1] nearly 99.6% of First Link paths, ending inside Wikipedia, lead to the Philosophy article (see traversal funnels discussion for details).

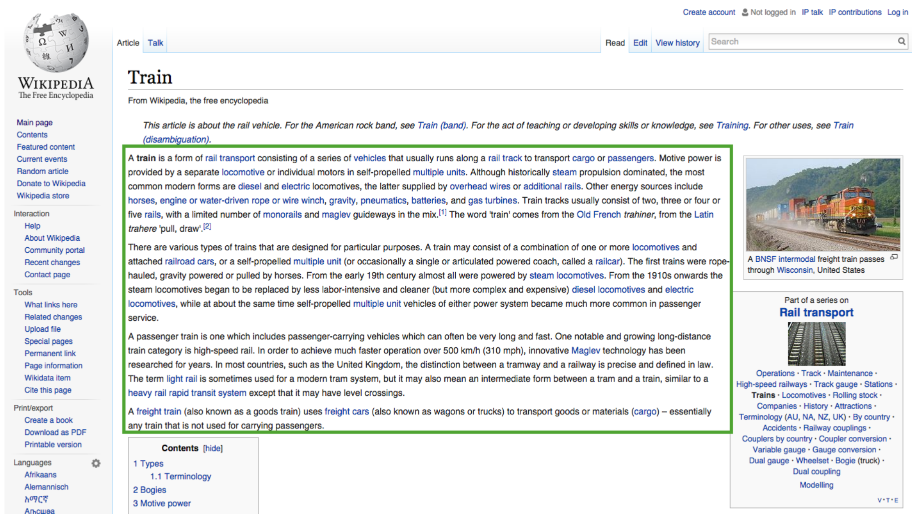
[2] An analysis performed in 2011 by Mat Kelcey posted on his blog (and a smiliar post by Ilmari Karonen) suggest 94.5% of articles end up at Philosophy.

[3] cite MIT Tech Review Article: http://www.technologyreview.com/featuredstory/520446/the-decline-of-wikipedia/

corresponds to the original claim in 2008 about the percentage of pages with First Links to "Philosophy."[4] [5] [6]

The result is a directed network placing every article in a broader web of ideas.

Figure 1: Wikipedia Train



I. Constructing the First Link Network

To map Wikipedia's First Link Network, we use the freely-available XML dump of the English edition of Wikipedia. Rather than rely on a sample of articles from which to generalize, we opted to process the entirety of Wikipedia, eliminating any statistical error due to sampling. We analyze the snapshot provided on November 2014, representing the state of Wikipedia at the time. The November raw dump consists of 11 million articles: 4.7 million unique articles along with redirects and disambiguations. Knowing Wikipedia is an ever-evolving project with 10 edits every second and 750 new articles per day on average ((cite)), our aim is to characterize the dynamics of the First Link Network, not record a particular link between one article and another.

Wikipedia renders and stores articles in MediaWiki markup, a markup langauge with syntax and keywords to format and mark elements in a page. Along with special syntax for links, MediaWiki markup includes templates for audio files, images, and side-bar information. While a human can accurately identify the First Link, to map the entire First Link Network of 11 million articles, we programmatically untangled the body text from side-bar, header box, and invalid link elements.

While some libraries exist for MediaWiki Markup, we opted to develop our own algorithm for parsing the First Link in the XML version of each article.[7] Our parsing algorithm aimed to: 1) accurately identify the First Link among other page elements 2)

[4] https://en.wikipedia.org/wiki/Wikipedia:GettingtoPhilosophy
[5] http://xkcd.com/903/
[6] https://www.reddit.com/r/pics/comments/gpdhb/trythiswikipediamindfk/
[7] Approaches using existing libraries led to several bugs including trouble with nested links, nested parenthesis, unclosed tags, escape characters as well as compatibility with other libraries used to parse the XML.

efficiently do so, without the need for several passes through the data. To process an article with one pass, we developed a hierarchical system of flags:

Figure 2: parsing algorithm of Wikipedia's XML dump

Parsing Algorithm

1: inside Wikimedia template?
trigger: {{ }}

2: inside <ref>, <div>?

3: inside ()?

valid link to Wikipedia article?

(a) The highest flag in the hierarchy indicates a Wikimedia template used to mark an element in the side bar, display an image, link to an external file, or another Wikimedia project outside of Wikipeida. Next, to catch any remaining elements outside the main body we have a second flag for <ref>, <div> elements. Finally, we catch parenthesis to ensure we do not capture a link to a pronunciation key.

The algorithm loops in three-character chunks to account for potentially nested elements, shifting by one character steps through the article markup. If any markup triggers for a flag are detected, a flag is raised. Once a flag is raised, we stop processing and proceed to the next character until the flag's closing markup. A First Link is identified only if Flags 1, 2, and 3 are all off. In this case, the entire link is retrieved. We then confirm the link is valid by filtering for MediaWiki keywords indicating external page or other projects as well as common file extensions for ((cite)) images, audio files, and the like. The First Link of an article is then the earliest valid link with unraised flags.

To process the entirety of Wikipedia, we distributed the parsing and processing of the XML dump across 112 cores of the UVM supercomputer cluster ((cite)) We then joined the results to form a hash table containing every Wikipedia article and its corresponding First Link. The resulting network map is the basis of our analysis.

II. Traversing the Network

To understand the structure of Wikipedia's First Link Network, we aimed to characterize the dynamics of the flow from one article to another. Do links tend towards a particular article, group of articles, or various groups of articles? What is the flow of links through a typical article? What types of cycle (loop) structures exist in the network? What are typical paths from one article to loop or an invalid link? Are there exceptionally long or short paths? Are there articles funneling the flow of links towards a particular path? In answering these questions about the directed network, we aimed to characterize how so many independent articles relate to each other.

The n-degree, or number of links directly pointing to a particular article, while a natural measure, fails to fully capture the dynamics needed to answer these questions. The n-degree measures only the particular set of links to a particular article, rather than the richer dynamics of how the links flow through the network: where articles tend, what the typical and atypical paths through the network are, which articles funnel relatively more links and so on.

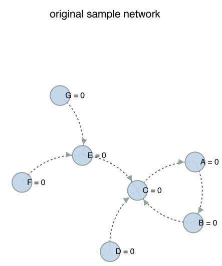
Consequently, to capture the dynamics of how the First Links flow, we actually traverse every possible path through the network. We developed three metrics to uncover structure: traversal visits, traversal funnels, and path length. Each metric captures one essence of how the links flow. Traversal visits gauge the accumulation of links; traversal funnels gauge the influence on link path; path length measures the number of First Links to a repeated or invalid link.

The algorithm for traversing the network begins by selecting any article. We then proceed to the next article by following the First Link—recalling a First Link is a link in the main body of the article leading to another Wikipedia article. We repeat until the First Link is invalid or repeated to form a path. The collection of articles is path-connected conveying a flow of concepts from one article to another. The method is order agnostic with respect to which articles are selected first. As long as each article is selected eventually, the resulting metrics are equivalent.

Figure 3: traversal visit algorithm on a sample network

Traversal Algorithm

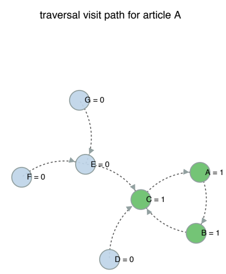
article		first link
A	→	B
B	→	C
C	→	A
D	→	C
E	→	C
F	→	E
G	→	E

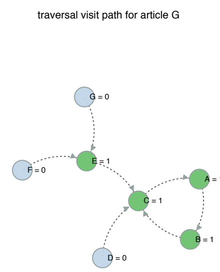


Traversal Visit Vectors

follow the first link path until a repeated article (or an invalid link)

$$\begin{bmatrix} \vec{A}_{\text{visit}} \\ \vec{B}_{\text{visit}} \\ \vec{C}_{\text{visit}} \\ \vec{D}_{\text{visit}} \\ \vec{E}_{\text{visit}} \\ \vec{F}_{\text{visit}} \\ \vec{G}_{\text{visit}} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$





The number of **traversal visits** for article $A = \sum_{i=1}^{i=7} \vec{A}_{\text{visit},\, i} = 7$

(sum of entries in $\vec{A}_{\text{visit}}$)

(a) The traversal visit vectors are an adjacency matrix for the paths through the network: the first column is indicates the path formed starting with article A. The number of traversal visits for article A is then the number of paths containing A or the sum of the first row in our matrix.

The first metric, traversal visits, gauges where the flow of first accumulates by associating a count to each article. Every path through the article increments the associated count by 1. We can construct a vector to represent the articles incremented on a particular path, combining these vectors to form a matrix. The total accumulated counts for a given article is then simply the sum of the row in our matrix corresponding to the article of interest. Node A in our example has 7 traversal visits, since every path includes article A. Whereas, node E only has two traversal visits since only two paths contain article E for example. What we have then is a metric signaling which article contains a larger accumulation of first links.

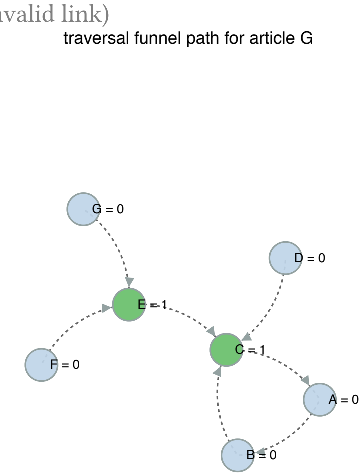
While traversal visits measure accumulation, we cannot gauge whether a particular article exerts a greater influence on flow of the first link paths. To distinguish between an article that simply happened to fall within a cycle from an article actually funneling the flow of first links, we developed a second metric called traversal funnels. We traverse the network in the same manner, but end our paths once we enter a cycle. We again increment the associated count of each article by one if the path up to a cycle contains the article. We call the accumulated count the number of traversal funnels. By measuring traversal funnels, we quantify which articles funnel more link paths in a particular direction or cycle.

Figure 4: traversal funnel algorithm on a sample network

Traversal Funnel Vectors

follow the first link path up the start of a cycle (or invalid link)

$$\begin{bmatrix} A_{\text{funnel}} \\ B_{\text{funnel}} \\ C_{\text{funnel}} \\ D_{\text{funnel}} \\ E_{\text{funnel}} \\ F_{\text{funnel}} \\ G_{\text{funnel}} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$



The number of **traversal funnels** for article $E = \sum_{i=1}^{i=7} \vec{E}_{\text{funnel},\, i} = 2$

(sum of entries in $\vec{E}_{\text{funnel}}$)

(a) The algorithm for traversal funnels is identical to the previous algorithm for traversal visits with one alteration: the path ends at the start of a cycle to distinguish articles directing a path into a cycle from articles that simply happen to be in a highly traversed path. We can construct similar vectors by considering each path through the network, measuring traversal funnels for a particular article as the sum of the entries in its corresponding row.

Finally, we track the number of links until a repeated article or invalid link, to find the typical path length within the network. By recording the history of articles we traversed, we are also able to uncover several other network charactersitics including basins, defined as a collection of path-connected articles ranked by traversal visits, and cycles of various lengths. The three metrics: traversal visits, traversals funnels, and path length, along with our path history yield a powerful arsenal of information with which to study the network.

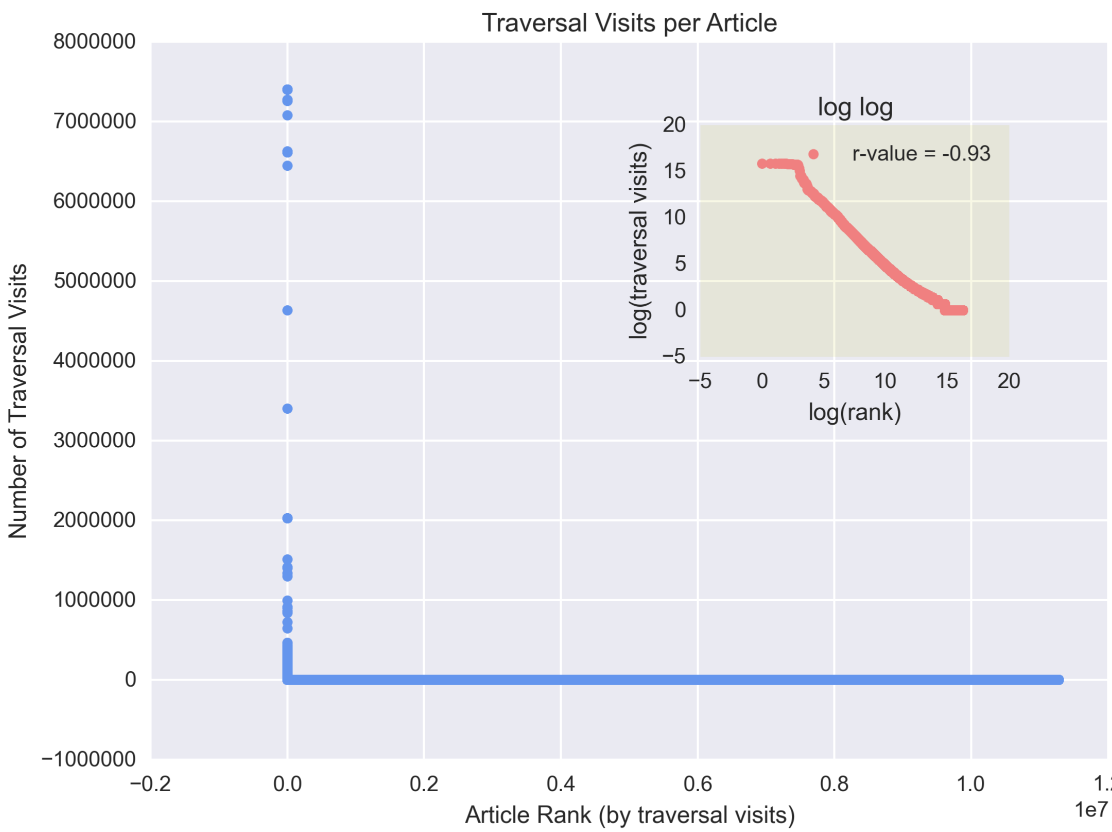
III. Discoveries

We followed every possible path through the network, taking 232 million steps along the way to measure the accumulated number of traversal visits.

III.1 Traversal Visits

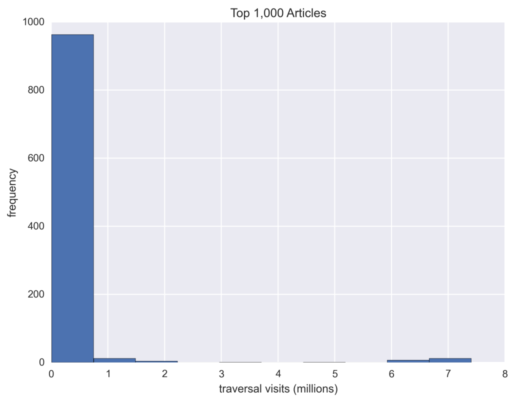
As a distribution, the number traversal visits per article appears scale-free. The majority of articles have fewer than 30 traversal visits, while few have 5 order of magnitude more traversal visits. Specifically, 99.76% of articles have fewer than 100 traversal visits; nearly 80% have none. Meanwhile, the highest ranking 30 articles have an extremely disproportionate number of traversal visits.

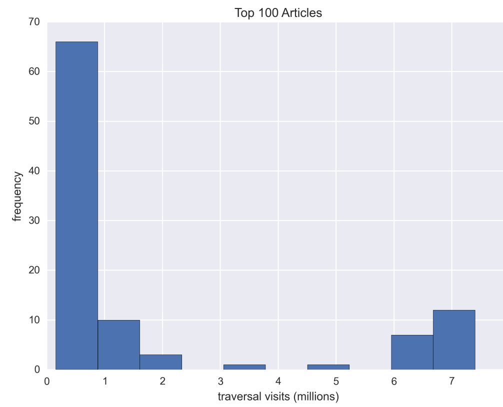
Figure 5: distribution of traversal visits



To more accurately gauge the distribution, we constructed a log-log plot of the entire dataset: log(traversal visits) against log(rank). We observe a fairly linear fit, as is characteristic of scale-free networks, with an r-value of -.93. A handful of the highest ranking articles contain a disproportionate number of traversal visits, while most have none. The skew in the distribution is not terribly surprising when considering the heuristic of how the links flow: from specific to general.

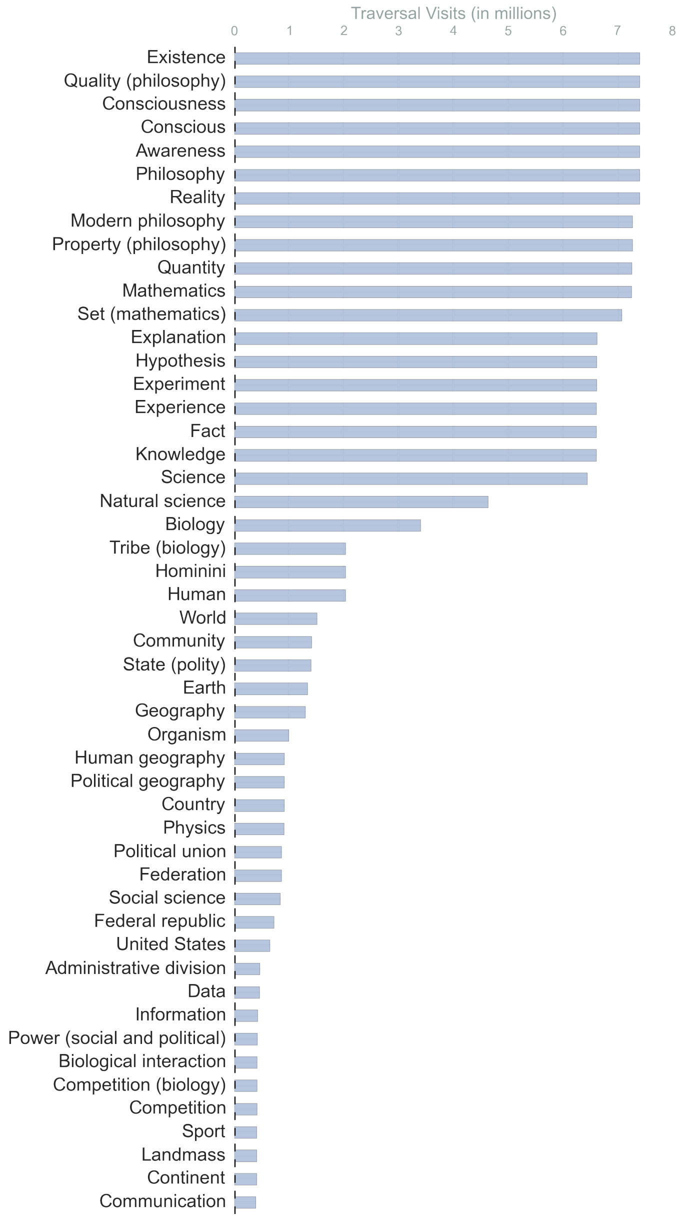
Figure 6: traversal visit distribution of highest ranking articles





The highest ranking articles include Philosophy alongside related articles such as "Existence", "Quality", and "Reality".

Figure 7: highest ranking articles by number of traversal visits



The recurrence of an exact number of traversal visits suggests some articles are part of a cycle. The "Philosophy" article for example sits in what seems like a cycle of seven other articles; "Hypothesis" appears to sit in a cycle of 6 other articles including "Experiment", "Fact", and "Knowledge". To confirm the suggested cycle structure, we recorded the history of articles traversed along a path.

III.1.1 A flow from general to specific

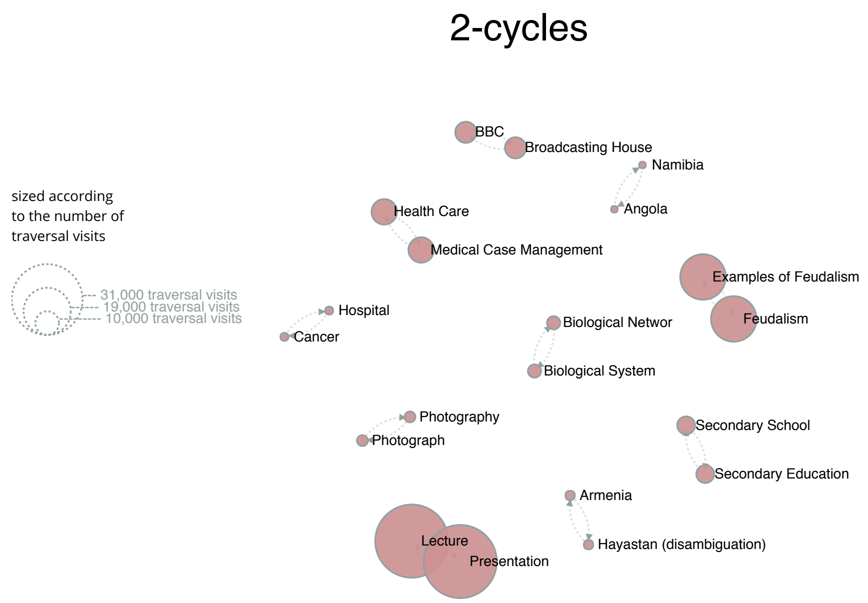
The highest ranking articles by traversal visits are broad, global topics: many are academic disciplines such as "Science," "Math," "Geography," "Biology," and "Physics"; others are abstract fundamental concepts such as "Community", "State", "Earth", "Information", "Communication", and "Power." Since traversal visits measure the accumulation of First Link visits in Wikipedia, the highest ranking articles suggest a flow from specific to general. For example the flow of First Links for the "Banana" article begins at a very concrete and specific topic then flows into progressively broader and broader disciplines, eventually culminating at "Philosophy: "Banana" links to the broader category of "Fruit," which then links to "Botany," eventually "Biology," then "Science" and ultimately "Philosophy."

One means to measure the specificity of an article is to identify the number of synonyms available for a word or topic. The reasoning here is that a broader topic likely has many more synonyms relative to a specific, concrete topic. Banana has fewer synonyms than botanical for example. To quantify the observed flow, we measured the number of synonyms the article title contained in WordNet—the largest lexical database of the English language. We find the highest ranking 100 articles have on average 5 more synonyms than the typical article; a difference of 2.5 synonyms if we compare the median number of synonyms in each group. As suggested by the median, many articles have no synonyms as we might expect, because titles with more than one word are not likely to appear in a thesaurus. Since many articles have no synonyms, we also compared the number of synonyms in the highest-ranking versus typical article, this time excluding all articles without at least 1 synonym. We still find the highest ranking 100 articles with an average of 9.0 (median of 7.0) synonyms whereas the remaining articles on average 5.8 synonyms (median of 7.0), even with the exclusion of all articles without any synonyms. The quantifiable difference in synonyms corroborates the flow of links from concrete, specific articles to broader disciplines or fundamental notions.

III.2 Network Cycles

By tracking the articles traversed we were able to identify the cycle structures by the reappearance of an article in our path history. We first identified 2-cycles, meaning a pair of articles with First Link pointing to one another. Of the 11 million articles, 84 thousand are 2-cycles. The highest ranking 2-cycles by traversal visits tend to be synonyms (or nearly so) rather than different, yet connected ideas: "Health Care" and "Medical Case Management", "Broadcasting House" and "BBC", "Secondary Education" and "Secondary School".

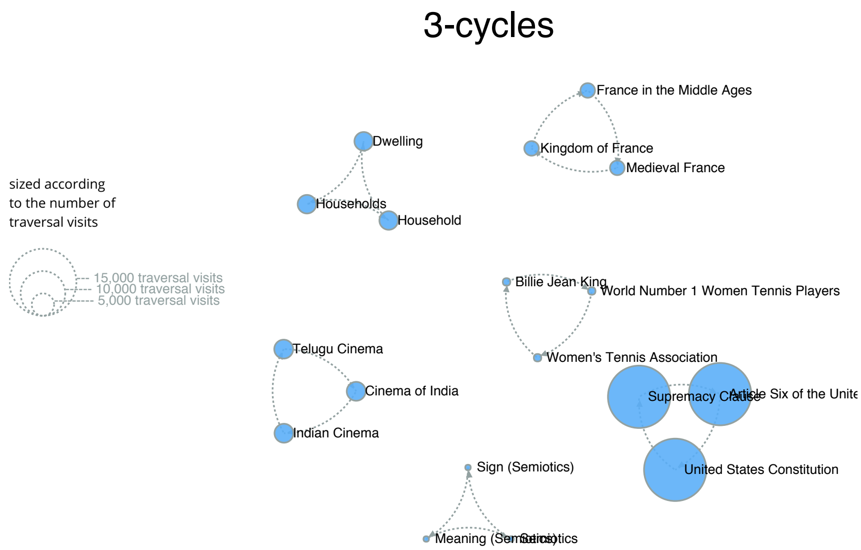
Figure 8: highest ranking 2-Cycles



Outside of the highest ranking 2-cycles, the typical 2-cycle signals a connection between different, yet very closely related ideas. Link patterns such as inventor to product ("Vo-ere" to "VEC-91"), event to organizer ("Poetry Bus Tour" to "Weave Books"), and book to author ("Anatomy of Britain" to "Anthony Sampson").

Similarly, 3-cycles captured a synonymous or close relation among 3 articles: "Tree of life (Biology)", "Tree of life (disambiguation)", and "Tree of life"; "Cinema of India", "Indian Cinema", and "Telugu Cinema". Once we extend our cycle size beyond a length of 6 however, "Philosophy" along with the remaining list of high ranking articles by traversal visits dominate.

Figure 9: highest ranking 3-Cycles

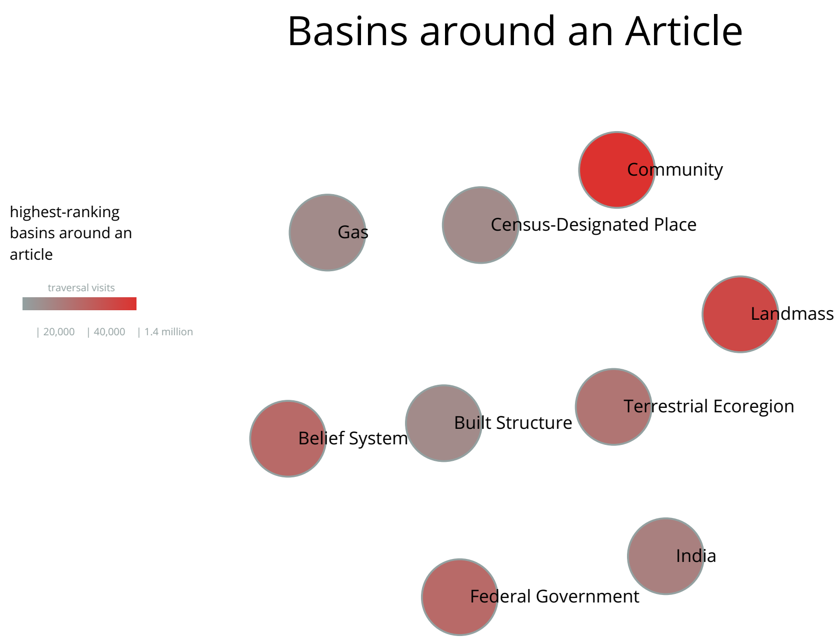


The longest cycle in the network spans 365 articles of Eastern Orthodox Liturgics for each calendar day. Curiously, on the last calendar day, the last article simply links back to January 1, forming a 365-cycle. Other lengthy cycles span 60-75 articles including collections of articles on national histories such as "Japanese Eras" or judicial bodies such as the "Legislative Assembly of Ontario".

III.3 Basins

We can group articles lying on the same path to identify basins of path-connected articles, not necessarily forming a perfectly closed cycle. Ranking basins by traversal visits, we find many of highest ranking basins are around "Philosophy" as we might expect. Looking beyond "Philosophy" however, we find high ranking basins around similarly foundational ideas: "Community", "Landmass", "Federal Government", "Presentation", and "Belief System". These concepts naturally emerge from the First Link Network potentially indicating pillars, which anchor specific knowledge in a broader, simpler concept.

Figure 10: highest ranking 3-Cycles



III.4 Path Length

In addition to identifying cycles and cycle lengths, we also measure the traversal path length, which includes articles outside of cycles. Path length measures the number of links traversed until a repeated or invalid link. We discovered the longest path length is also 365, matching the longest cycle of Orthodox Liturgics. We also found similarly lengthy paths following the evolution of a place or topic through time: "1953 in Scotland" or "1560s Architecture", with articles sequentially proceeding by year, decade or era.

Of the 11 million articles, 5.5 million had an invalid link or linked back to the same article, yielding a path length of zero. The most common path length is 29, with an interquartile range (26, 30). The distribution of path lengths is similarly scale-free with few articles at the extreme of 365 path lengths, while the majority is between 26-30:

Figure 11: Path Length Distribution

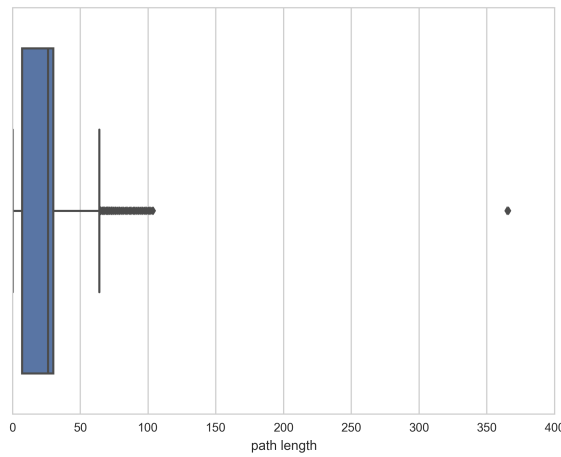
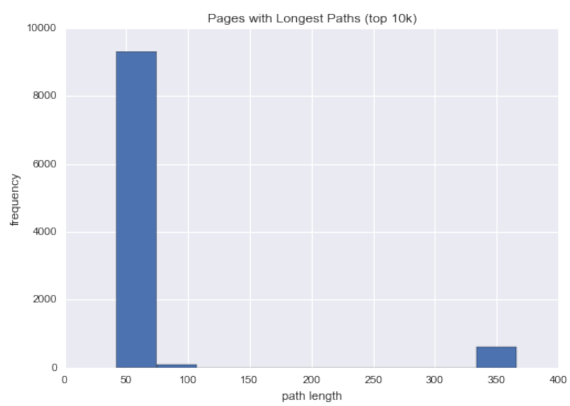


Figure 12: Longest Path Lengths

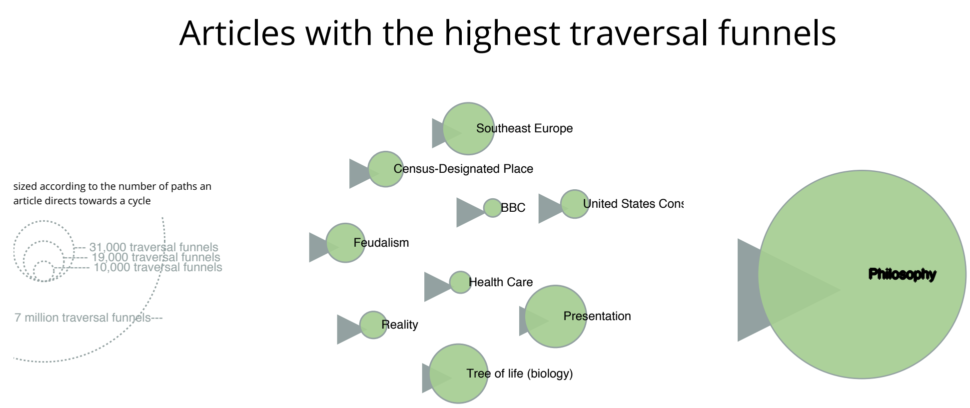


III.5 Traversal Funnels

Measuring only traversal visits however is limiting as it does not distinguish whether a particular article in a cycle is a funnel, directing many more paths inside the cycle than others. To distinguish among articles in a cycle, we also measured traversal funnels, or the number of paths an article directs towards a cycle. Here we count the number of traversal visits up to a cycle, so that accumulation does not flow to all articles in a cycle. The importance here is to distinguish an article that happens to be connected to another article with many traversal visits from an article directly funneling many paths.

Measuring traversal funnels reveals a dramatically different structure where "Philosophy" stands unmatched by orders of magnitude:

Figure 13: Top Funnels



Philosophy is not only a stand out the number of traversal visits, but also by the number articles "Philosophy" funnels into its cycle. Of any article, the number of traversal funnels Philosophy holds exceeds all others by at least two orders of magnitude. Next to the contribution of the largest funnels, "Philosophy" is a singularity. In proportion, "Presentation" holds only 0.4% next to the number of traversal feeds for "Philosophy". The second contributor to the Philosophy cycle is "Reality", funneling in a mere .2% of traversals visits in the cycle. Nevertheless, the other high ranking funnels are remarkably topical, culturally and politically important ideas. For example, "Health Care", a recently high-contested legislative topic appears high on the list—Google trends indicates an uncharacteristic spike in search frequency between August-2009 and February-2010. Other high ranking articles include key historical events such as the "Cold War" or critical scarce resource with recent media discussion such as "Fossil Fuel". This coincidence of recent relevance and traversal feed rank suggests the First Link Network measurably represents meaningful relationships not only among ideas, but also to English-speaking society.

IV. Reflections

The findings here should only be considered within the limitations of their context. We examined only the English version of Wikipedia at a particular moment in time. Furthermore, we only studied the First Link in the main body of each article as a means to related one article to another. Finally, Wikipedia, while the largest collection of human knowledge, is rife with the biases of the many contributing editors ((cite)) . Nevertheless, the findings do reveal generalizable relationships, point to foundational notions, and uncover many curiosities.

Among the curiosities is the multiple appearance of scale-free distributions within the network. The three metrics we developed: path length, traversal visits, and traversal funnels are all marked by scale-free distributions. Few articles have most traversal visits, few paths have an exceptionally long path length, and even fewer articles are responsible for funneling most paths. When measured against the traversal funnels, "Philosophy" emerges as an exceptional article by orders of magnitude. Nevertheless, many other foundational ideas emerged naturally within the First Link Network. Basins around "Community", "State", and "Science" reveal a foundational structure within the network. More curious is the emergence of recently prominent political and economics topics such as "Fossil Fuel" and "Health Care" within the highest ranking funnels. Wikipedia seems to reflect not only timeless foundations, but also the topical (at least within English speaking society).

Future work could analyze other language versions of Wikipedia for potentially telling cultural or regional differences as well as expand the network beyond the First Link to a subset or potentially all links. These findings also form the basis for the creation of a taxonomy where every idea, event, or object sits within a hierarchy of connected notions. The taxonomy would extend a traditional word thesaurus beyond mere synonyms to a related hierarchy of concepts. Applications could range from an enhanced thesaurus of ideas to psychological insights into how humans form associations. Specifically, an ever-evolving reference of related hierarchical concepts can be applied to search engine algorithms or natural language processing.

- thank you to my friend RJ for pointing out the xkcdc comic about links to Philosophy

V. Supplementary

Figure 14: highest ranking 2-Cycles

	page	path length	visits
5918	Lecture	2	31000
58203	Presentation	2	31000
44072	Report	2	30771
23737	Examples of feudalism	2	19280
52724	Feudalism	2	19280
69026	Dynasty	2	15833
67007	Health care	2	10777
56597	Medical case management	2	10777
47675	Broadcasting House	2	8952
19184	BBC	2	8952
43228	Secondary education	2	7563
36797	Secondary school	2	7563
13436	Dam	2	7043
28743	Reservoir	2	7043
53676	Biological network	2	5574
79245	Biological system	2	5574
24215	Circulatory system	2	5266
80703	Photography	2	4594
11189	Photograph	2	4594

Figure 15: highest ranking 2-Cycles

	page	path length	visits
2558	Balkans	3	32333
71197	Balkan peninsula	3	32333
41373	Southeast Europe	3	32333
13023	Narrative	3	30716
33929	Tree of life (biology)	3	29302
20874	Tree of life (disambiguation)	3	29302
29882	Tree of life	3	29302
3043	Tree of life (science)	3	29266
11563	United States Constitution	3	13968
10199	Supremacy Clause	3	13968
69587	Article Six of the United States Constitution	3	13968
41849	Bulgaria	3	9719
65328	Order (honour)	3	8663
66125	Article Three of the United States Constitution	3	7591
8642	Southeastern Europe	3	6107
73868	Albania	3	5773
36667	List of Presidents of the United States	3	4485
51710	Cinema of India	3	4228

Figure 16: Top Funnels

	page	feeds
7948850	Philosophy	7374892
224026	Presentation	30799
9030902	Tree of life (biology)	29274
1344349	Southeast Europe	25745
11029885	Feudalism	19276
632584	Census-Designated Place	17483
7652704	United States Constitution	13952
7974918	Reality	13416
8629119	Health care	10762
7739754	BBC	8945
7580925	Hip Hop Music	7166
4495967	Consciousness	6587
5516532	Balkans	6547
3381363	Quality (philosophy)	5712
5866358	Biological system	5568