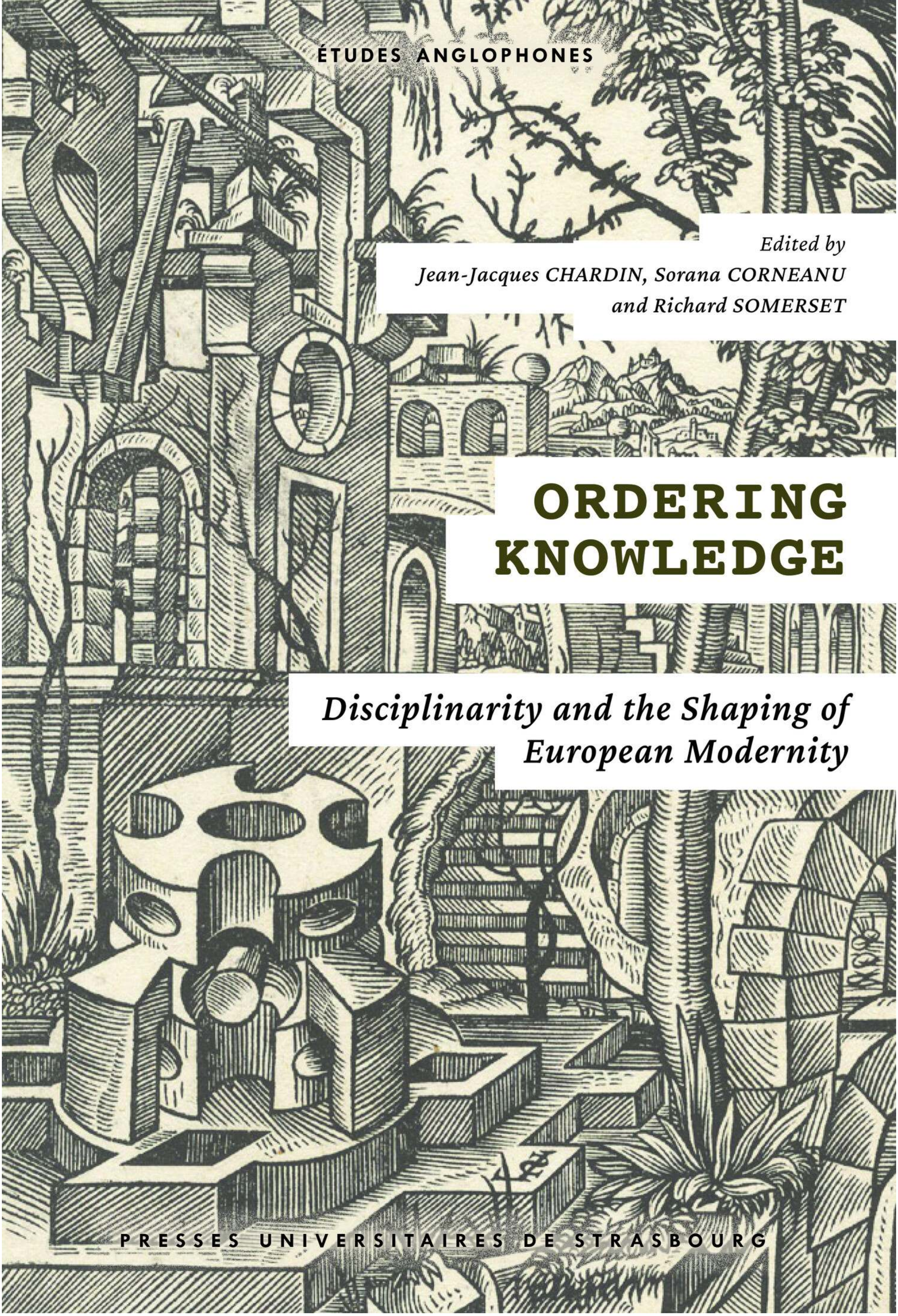
ÉTUDES ANGLOPHONES



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*and Richard SOMERSET*

# ORDERING KNOWLEDGE

## *Disciplinarity and the Shaping of European Modernity*

PRESSES UNIVERSITAIRES DE STRASBOURG

Presses universitaires de Strasbourg

# Ordering Knowledge

## Disciplinarity and the Shaping of European Modernity

**Jean-Jacques Chardin, Sorana Corneanu and Richard Somerset (dir.)**

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Publisher: Presses universitaires de Strasbourg
Place of publication: Strasbourg
Year of publication: 2023
Published on OpenEdition Books: 3 May 2023
Series: Études anglophones
Electronic EAN: 9791034403615

https://books.openedition.org

**Printed version**
Date of publication: 3 May 2023
EAN (Print version): 9791034401338
Number of pages: 344

**Electronic reference**
CHARDIN, Jean-Jacques (ed.) ; CORNEANU, Sorana (ed.) ; and SOMERSET, Richard (ed.). *Ordering Knowledge: Disciplinarity and the Shaping of European Modernity.* New edition [online]. Strasbourg: Presses universitaires de Strasbourg, 2023 (generated 03 mai 2023). Available on the Internet: <http://books.openedition.org/pus/32660>.

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# ‘The Whole Set to View’: Orders of Knowledge in Chambers’ *Cyclopaedia*

Seth Rudy

In his 1726 ‘Proposals for printing by subscription, *Cyclopaedia, or an Universal Dictionary of Arts and Sciences*’, Ephraim Chambers wrote that the ‘system’ of references in his projected work would finally ‘set to view’ the whole of human learning by enabling the many parts of knowledge scattered by alphabetical order to be put back together into a complete circle of arts and sciences.[1] That system became the basis of a generic and hierarchical divide between encyclopaedia and dictionary – a divide advanced by subsequent British encyclopaedists and monumentalized in the far more extensive *renvois* employed by Denis Diderot and Jean le Rond D’Alembert. The cross-referencing systems of the century’s major encyclopaedias have attracted ample attention; scholars have observed, for example, their innovative but inconsistent use in the two-volume *Cyclopaedia*; their tactical subversion of religious and scientific orthodoxy in the French *Encyclopédie*; the genuinely productive connections they facilitate in both; and their eventual rejection by William Smellie, who opted to organize the first edition of the *Encyclopaedia*

1. Ephraim Chambers, *Proposals for Printing, by Subscription, Cyclopaedia, or an Universal Dictionary of Arts and Sciences* (London: 1726), 1:i.

*Britannica* around a series of self-contained Systems and Treatises more closely aligned with what would become the modern disciplines.[2]

This study, however, will focus on several views of Chambers' system that have escaped critical notice because they could not be seen. Cross-references facilitate following pathways through specific areas of inquiry but can obscure the scope and organization of the reference system, and therefore of the encyclopaedia, as a whole. As Chambers acknowledges, the 'whole Land of Knowledge' that the system seeks to lay open 'appears indeed with the face of a Wilderness, but 'tis a Wilderness thro' which the Reader may pursue his Journey as securely, tho not so expeditiously and easily, as thro' a regular Parterre.'[3] This assurance acknowledges the problem of scale that typically emerges in attempts to organize and disseminate what to individual readers must seem like large amounts of information. As Gilles Blanchard and Mark Olsen remark in their study of *renvois* in the *Encyclopédie*, the structure of such a reference system is by its nature elusive – tedious to reconstitute one link at a time and seemingly impossible to envisage in its totality.[4] To put it in Chambers' terms, the 'security and regularity' perceptible at the level of a single entry or limited series of entries recedes from view as that series expands to incorporate more, and more disparate, information. Simply put, readers from the eighteenth century on have all had to work with less than a complete picture of Chambers' reference system.

Network visualization and analysis, however, can map that wilderness and help researchers to navigate the space between forest and trees.[5] Towards that end, I conducted a page-by-page audit of the text and manually compiled a

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2. See, for example, Richard Yeo, *Encyclopaedic Visions* (Cambridge: Cambridge University Press, 2001); Robert Darnton, *The Business of Enlightenment: a Publishing History of the Encyclopédie* (Cambridge: Belknap Press, 1979); Frank Kafker, 'Smellie's Edition of the *Encyclopaedia Britannica*,' in *Notable Encyclopedias of the Late 18th Century: Eleven Successors of the Encyclopédie*, ed. Frank Kafker (Oxford: Voltaire Foundation, 1994).
3. Chambers, *Cyclopaedia* (London: 1728), 1:i.
4. Gilles Blanchard and Mark Olsen, 'Le système de renvois dans *l'Encyclopédie*: Une cartographie des structures de connaissances au XVIII^e siècle,' *Recherches sur Diderot et sur l'Encyclopédie* 31–32 (April 2002): 47.
5. I would like to thank Mark Algee-Hewitt, Director of the Stanford Literary Lab, for his time and tutorials on network analysis in general and this project specifically.

two-column dataset with headwords (the words under which entries appear in text) in the first column and the headwords to which those entries are cross-referenced in the second (tab. 1). This method, though inevitably subject to error, helped to avoid or overcome some of the problems with a computational approach, particularly with respect to variations in the language used to indicate cross-references.[6] Some data nevertheless required correction; for example, pluralized cross-references sometimes refer to singular headwords and vice-versa (e.g., the entry under AGGLUTINANTS directs readers to see MEDICINES, but the actual headword is MEDICINE, and multiple entries direct readers to see AGGLUTINANT). These were emended to reflect the headwords as they appear in the text.

**Table 1. Source-Target list, a sample**

| Source | Target |
|---|---|
| Amalgam | Mercury<br>Metal<br>Lead<br>Transmutation<br>Philosopher's Stone<br>Amalgamation |
| Amalgamation | Amalgama<br>Mercury<br>Metal<br>Gilding<br>Gold<br>Character |
| Amatorii | Eye<br>Abductor<br>Humilis |
| Amaurosis | Eye<br>Gutta |
| Amaxobii | Hamaxobians |

6. Blanchard and Olsen, 'Le système de renvois,' 55.

Other problematic data, in contrast, have gone unaltered. As in the *Encyclopédie*, polysemous headwords present an organizational conundrum; many cross-references lead to entries with multiple, subject-specific subsections. Chambers often left readers to determine as best they could which he might have meant. Complicating matters still further, referencing practice in the *Cyclopaedia* changed between volumes. Whereas volume one divides entries into subsections beneath a single headword, volume two records subject-specific explanations under repeated, identical headwords. WATER, for example, appears four times: first in relation to physics, then anatomy, religion, and jewellery-making. Rather than combine them, I entered them into the dataset as numbered iterations (e.g., Water 1, Water 2, etc.).[7] Dividing the waters this way better reflects the organizational course-correction Chambers made halfway through the project.

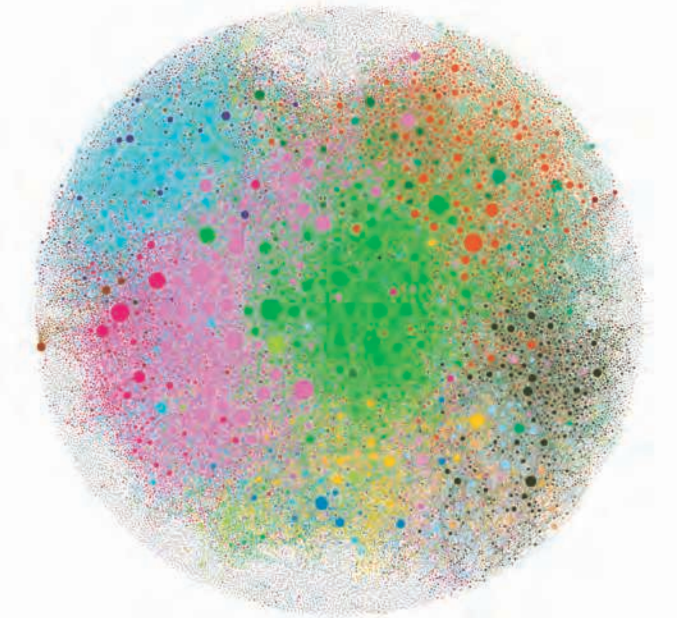

**Fig. 1. Full Network Diagram of the *Cyclopaedia*, 1728**

7. Out of 7176 headwords in volume 2, only 108 appear more than once.

The finished dataset contains 13,459 headwords and 39,367 cross-references. These numbers alone change what we know about the system. In *Encyclopedic Visions*, Richard Yeo claimed that Chambers 'cross-referenced about half' of the articles in the *Cyclopaedia*; scholars have since repeated the estimate without comment.[8] This data, however, show that 10,266 entries in the first edition (including the addenda at the end of the second volume) contain one or more cross-references.[9] Rather than around half, then, just over three quarters (76.3%) of entries have both in- and outgoing references. A further 859 (6.4%) are termini: entries referred to but not referring to others. Only 2,329 (17.3%) are 'island' entries entirely disconnected from the network. If both of the first two categories count, then fully 82.7% of the collection is cross-referenced, and the system is much more thoroughly networked than previously believed.

Though these figures offer a more accurate account, they by themselves do little to clarify the *Cyclopaedia*'s intricacies or provide insight into more general structures and characteristics, and as a list of data points, the nearly 40,000 cross-references constitute another order of wilderness. Figure 1 displays the system as a directed network diagram made using Gephi, an open-source network analysis and visualization software package.[10] The diagram represents headwords as connection points (nodes) and the cross-references as the lines between and among them (edges). As a directed graph, each edge also has an arrow indicating the direction of the cross-reference: from the article containing the reference, to the article that was referenced. Though difficult to parse at a glance, a critical exploration of the diagram and underlying data do illuminate otherwise undetectable dynamics and structures in Chambers' system.[11] Setting the whole to view and analysing

8. Yeo, *Encyclopaedic Visions*, 132; also Jeff Loveland, 'Unifying Knowledge and Dividing Disciplines: the Development of Treatises in the "Encyclopaedia Britannica",' *Book History* 9 (2006): 62.
9. This number includes self-referential entries.
10. M. Bastian, S. Heymann, and M. Jacomy, 'Gephi: an open source software for exploring and manipulating networks,' International AAAI Conference on Weblogs and Social Media, 2009.
11. In network analysis, such dense and difficult-to-decipher visualizations are called 'hairballs' or 'spaghetti monsters'.

the network reveals which subjects in the *Cyclopaedia* remained largely separate from each other and which were more closely connected, which terms obtained across multiple areas of learning, and which were shifting in their associations from old to new paradigms. It furthermore discovers a prehistory of modern disciplinarity latent in a foundational exercise in Enlightenment information organization.

## THE PERSISTENCE OF VISION

Modern methods of data visualization constitute a continuation of Enlightenment reading, writing, and scholarly practices rather than a departure from them.[12] During the eighteenth century, authors frequently relied on image and text – especially in collections with large amounts of theoretically unified but organizationally disaggregated information – to help correlate data and sense.[13] Chambers included a branching diagram reminiscent of medieval and Early Modern 'trees' designed to represent the order of knowledge (fig. 2). His own categorized knowledge as 'either "Natural and Scientifical," or "Artificial and Technical," and separated into further subdivisions' in accordance with Ramist methods.[14] That he included such a conventional device on page two of an encyclopaedia celebrated for its innovative organizational system, and that he did so despite understanding that the distinctions between arts and sciences were 'not yet well fixed', speaks to the value he placed on representing the order of knowledge graphically.[15]

12. On issues of authority and transparency, see Joanna Drucker, 'Humanistic Theory and Digital Scholarship,' in *Debates in the Digital Humanities*, ed. Matthew K. Gold (Minneapolis: University of Minnesota, 2012), 85–95; also Joanna Drucker, 'Humanities Approaches to Graphical Display,' *Digital Humanities Quarterly* 5, no 1 (2011).
13. See, for example, John Bender and Michael Marrinan, *The Culture of Diagram* (Stanford: Stanford University Press, 2010); Daniel Rosenberg and Anthony Grafton, *Cartographies of Time: a History of the Timeline* (New York: Princeton Architectural Press, 2010); and Manuel Lima, *The Book of Trees: Visualizing Branches of Knowledge* (New York: Princeton Architectural Press, 2014).
14. Yeo, *Encyclopaedic Visions*, 132–33. On branching diagrams in medieval manuscripts and early modern print, see Ann Blair, *Too Much to Know: Managing Scholarly Information before the Modern Age* (New Haven: Yale University Press, 2010), 144–52.
15. Chambers, 'Science,' *Cyclopaedia*, vol. II; quoted by Yeo, *Encyclopaedic Visions*, 135.

His emphasis on the visual, however, went well beyond this diagrammatic 'View of Knowledge'. The preparatory and prefatory materials of the *Cyclopaedia* are rife with visual language. The word 'view' by itself occurs 25 times in the 30 pages of the preface. Though it most frequently appears in senses related to plans and designs ('the view in the present work') or mental rather than ocular perspective ('moral view'), the preface gives pride of place to usage that figuratively and literally invokes sight as the preeminent faculty of knowledge acquisition – a position held in European scientific and philosophical thought throughout the medieval period and Renaissance.[16]

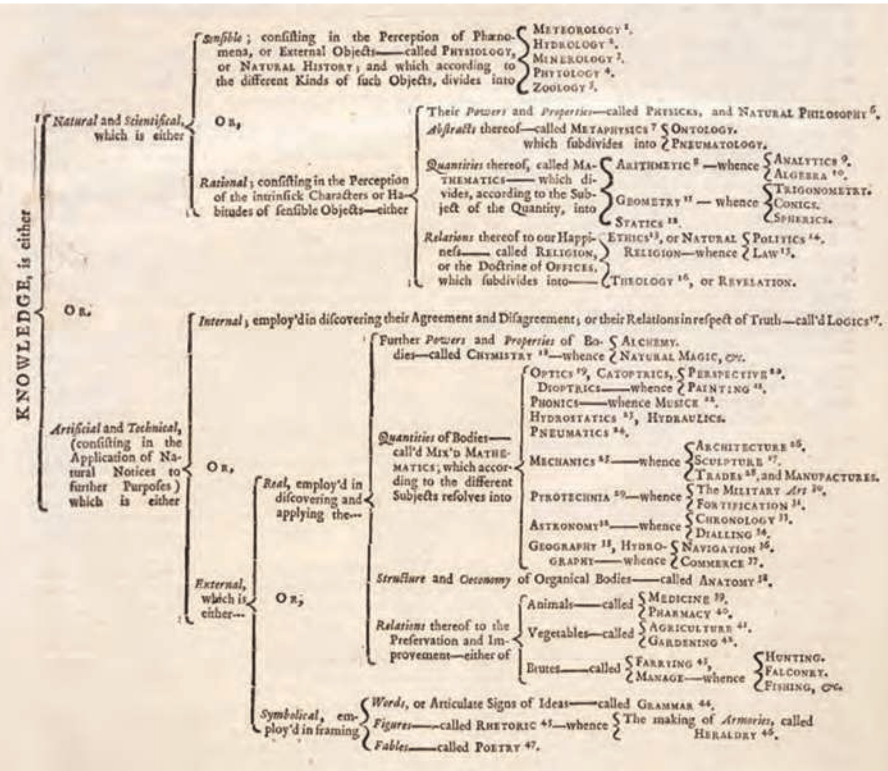


**Fig. 2. Chambers' "View of Knowledge", from the preface to his *Cyclopaedia*, 1728**

16. Stuart Clark, *Vanities of the Eye: Vision in Early Modern Culture* (Oxford: Oxford University Press, 2007), 9–19.

From the outset, then, Chambers attempts to frame the macro- and micro-levels of encyclopaedic organization as not only finally comprehensible but also physically perceptible. He dedicates an early paragraph to describing language as a 'kind of second Sense' by which 'we hear Sounds made a thousand Years ago and see Things that pass a thousand Miles off.' Language, he continues, extends the hearing, smell, and sight of humankind 'over the whole Globe'.[17] His explanation tellingly refers to sight and seeing three times but mentions hearing and smell only once. This emphasis on vision extends throughout the opening pages. Indeed, the invocations of wilderness and parterre quoted above, in which 'the land of knowledge' has a 'face' that 'appears' to the reader, come from the preface's very first page, immediately following the initial introduction of the reference system.

The metaphors produce what may seem a conventional blurring of distinctions between intellectual or abstract 'views' of the text and a physical view of the book as material object, but two sentences later Chambers explains the virtue of his encyclopaedia in a still metaphoric but now more material and mechanistic way that further stresses the importance of sight and the status of print as a visual medium. 'In any other Form,' he insists, 'many thousand Things must necessarily be hid and overlook'd; All the Pins, the Joints, the binding of the Fabrick must be invisible.'[18] The references are those pins and joints; they alert readers to the connections that exist between various terms and parts of knowledge disaggregated by alphabetic order. Prior to a reading of the indicated articles, though, the references have little or no content beyond their status as linguistic signifiers. They thus constitute an almost constant and self-referential reminder of the links between text, vision, and knowledge.

While not necessarily new to eighteenth-century English audiences either in their function or in their linguistic association with sight – Thomas Cooper, for example, had in his *Thesaurus Linguae Romanae et Britannicae* (1565) used the Latin *vide* (to see) to point readers to additional sources of information – the cross-referencing of the *Cyclopaedia* makes the word 'see'

17. Chambers, *Cyclopaedia*, 1:vi.
18. Chambers, *Cyclopaedia*, 1:i.

a regular feature on most of its more than 2,000 pages.[19] In more heavily cross-referenced sections or subjects, readers might be instructed to 'see' various subjects dozens of times over the course of a single page or even a single column.[20] The references in and of themselves thus command repeated and instantaneous attention; they are components not to be overlooked, but rather to be looked at as crucial elements of the work. The word 'see' in essence makes the system visible, and its visibility facilitates the readers' mental reconstitution of a larger 'view' of knowledge.[21]

Such a view could not be otherwise produced. Chambers had acknowledged the impracticality or even impossibility of depicting all knowledge at once in the proposal for the *Cyclopaedia* published two years prior. ''Tis a scene of such Extent and Variety', he explains, 'that a Representation of it in little, wou'd confound the Eye rather than inform it.'[22] If this comment 'almost anticipates Bentham's lament about the difficulty of visually representing complex relationships between parts of knowledge,' then it also confirms Chambers' having at least imagined what such a representation might look like and further speaks to the possibility of his having at some stage contemplated its manufacture and inclusion.[23]

He was nonetheless compelled to justify its limitations. The diagram exhibited 'only the grand, constituent parts thereof. It would be endless to pursue it into all its Members and Ramifications, which is the proper business of the Book itself.'[24] A similar compromise occurs on the following page, when the Principal Heads 'come in sight' to present 'the dispersed Materials of the Book in one view'.[25] That 'one view' spreads the 47 main subjects and abbreviated lists of the terms belonging to them over four

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19. Cooper's is the earliest example of this usage listed in the *OED*. 'vide, v.2', OED Online, June 2018, Oxford University Press, http://www.oed.com/view/Entry/223255?rskey=3pnJyb&result=2 (accessed June 14, 2018).
20. 'See' occurs, for example, 31 times on page 61.
21. 'See' is not the only indicator of a reference in the text but it is by far the most common.
22. Chambers, *Proposals*, 26.
23. Yeo, *Encyclopaedic Visions*, 132.
24. Yeo, *Encyclopaedic Visions*, 133; Chambers, *Cyclopaedia*, 1:ii.
25. Chambers, *Cyclopaedia*, 1:iii.

pages and arranges them into a 'directory' indicating the order in which Chambers thought they should be read. The language in both cases invokes the idea of a single cohesive representation of the entire structure, but both his diagram and his directory leave gaps that fall to the reference system to bridge. Chambers, in short, seems to have wanted a more complete visualization of the *Cyclopaedia* than he could provide. The system he devised could set the whole to view, but only in the mind's eye.[26]

As subsequent encyclopaedists pointed out, this did not actually work. Despite the success of the *Cyclopaedia* and the adaptation of its reference system in the *Encyclopédie*, the proprietors of the *Encyclopaedia Britannica* in 1768 proposed to do away with cross-references precisely because of the burdens they placed on memory and imagination. 'Every art and science', they wrote, 'lies scattered under a variety of words; by which means, besides the labour of hunting for science through such a labyrinth, it is absolutely impossible for the reader, after all, to obtain a distinct view of any subject.'[27] The word 'view' once again links the mental and the material through the language of sight: physically scattering the words in the book diminishes the clarity of understanding in the mind. William Smellie, editor of the first *Britannica*, sought to solve this problem by composing sustained 'Treatises or Systems' of single subjects. As Clifford Siskin explains, the change signalled more than just a shift in genre conventions:

> The end result…was nothing less than to enact the turn into modernity presaged by *Britannica's* editions: a transformation in the ways of knowing from the Enlightenment organization of knowledge in which every kind was

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26. 'the most advantageous way, is to make use of both Methods: To consider every point as a part; to help the Imagination to the whole: and as a Whole, to help it to every part – Which is the View of the present Work – so far as the many and great Difficulties we had to labour under would allow us to pursue it.' Chambers, *Cyclopaedia*, 1:ii.
27. 'Proposals for printing, by subscription, a work, intitled, *Cyclopaedia*; or, A new and complete dictionary of arts and sciences' (Edinburgh, 1768), n.p.

> a branch of philosophy, moral or natural, into our present organization: narrow but deep disciplines detached from each other and then divided between what we now know as the humanities and sciences.[28]

The inability to form a cohesive, comprehensive, and comprehensible 'view' – either graphically or cognitively – of even a single subject, let alone a master system like the one incompletely illustrated by Chambers' diagram, led Smellie to redefine encyclopaedic systematicity in such a way that elevated the priority and visibility of individual subjects.

Though attempts to visualize master systems of human knowledge fell out of favour, developments in data visualization continued to accelerate during and after the Enlightenment. In the nineteenth century, mathematics took centre stage as a means of overcoming the material limits of print culture as well as those of the human sensorium with ever more abstract but nonetheless useful descriptions of the world.[29] The unfolding of this 'diagrammatic turn' is itself linked conceptually and methodologically to 'the network turn' described by Ruth Ahnert, Sebastian E. Ahnert, Catherine Nicole Coleman, and Scott Weingart in their recent book of the same name.[30] Emerging around the turn of the millennium from 'a whole host of converging thoughts and practices', the ways in which we think about information, connectivity, systems, and knowledge have shaped and been shaped by 'the zeitgeist of a networked age'.[31] Scholars in the arts and humanities have accordingly begun to make more use of 'network vizualisation, social network analysis theory, and quantitative measures from network science to address their research questions.'[32]

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28. Clifford Siskin, *System: the Shaping of Modern Knowledge* (Cambridge, MA: MIT Press, 2016), 129.
29. Bender and Marrinan, *The Culture of Diagram*, 152–53, 197.
30. Bender and Marrinan, *The Culture of Diagram*, 199.
31. Ruth Ahnert, Sebastian E. Ahnert, Catherine Nicole Coleman, and Scott B. Weingart, *The Network Turn: Changing Perspectives in the Humanities* (Cambridge: Cambridge University Press, 2020), 3.
32. Ahnert *et al., The Network Turn*, 5–6.

As a device specifically deployed to ‘help the Imagination to the Whole: and as a Whole, to help it to every Part,’ the *Cyclopaedia*’s cross-references clearly invite such treatment.[33] Network visualization and analysis facilitates a study of the cross-references from single node to entire system. The remainder of this chapter, then, will use the diagrams and data as guides to and through Chambers’ labyrinth by examining the features and functions of degree centrality, layout, and modularity analysis. The first two determine the size of individual nodes and how to position those nodes and their connections in two-dimensional space; the third attempts to assess how the network may be fragmented into distinct modules or ‘communities’ made up of highly-connected nodes. All three transformations have virtues and limitations. The diagram is not the network, but rather an interpretation of it: features can be adjusted to highlight different variables, and the correlation of visualization and underlying mathematical object is not always exact.[34] Chambers’ branching diagram, though, was similarly (as he put it) ‘artificial’. The new view and data discussed below, then, follow in the same tradition. Together, they provide a space in which to explore questions about the order of the arts and sciences as actually systematized within the *Cyclopaedia*.

## DEGREE CENTRALITY

Nodes in the diagram are sized according to ‘degree centrality’, or ‘degree’ for short: the total number of connections they have to other nodes. The more incoming and outgoing references an entry has, the higher the degree and the larger the node representing its headword appears. Degree measurements offer the simplest way of measuring the ‘importance’ of a node within a network. The low number of large nodes immediately indicates how few entries have high numbers of direct connections to others. The data makes this even clearer: only 24 entries out of nearly 13,500 in the text have more than 100 combined incoming and outgoing references; the overwhelming

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33. Chambers, *Cyclopaedia*, 1:ii.
34. Ahnert *et al., The Network Turn*, 68.

majority (88.9%) have fewer than ten. This result is not in itself surprising, as 'many varieties of observed networks across very different contexts display a highly skewed distribution of degrees.'[35] Nevertheless, the picture that emerges from the data appears to reflect and reinforce the importance of some subjects while diminishing that of others.[36]

Table 2 lists the top 20 nodes by degree. 'Earth', at 176 (79 outgoing references, 97 incoming), is the most cross-referenced entry in the system, followed closely by 'Air' at 165 (73 outgoing, 92 incoming). 'Point' and 'Circle' bottom out the list with degrees of 111 and 110, respectively. Adjusting the metric alters the results, but not by much: counting only the number of cross-references an entry contains (outdegree) or only the number of times a headword is cross-referenced by other entries (indegree) slightly reorders the top 20 and introduces a few new terms. A list ranked by outdegree sees 'Angle' in the top position at 103; the entries for 'Architecture', 'Drug', and 'Arms' respectively appear in the 11th, 16th, and 20th positions. Measuring only by indegree, in contrast, introduces the headwords CHARACTER, COIN, FEAST, HEAT, and STONE. GOD also makes the list, albeit in the lowest position. The node with the highest indegree is Measure, to which Chambers' system directs readers 109 times. Reviewing the data and rereading the entry reveal not only the number of fields defined by measures and measurements, but also the different kinds of measurement by which the universe is known and in accordance with which much of human activity is conducted.

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35. Ahnert *et al.*, *The Network Turn*, 79; see also Scott Weingart, 'Networks Demystified 3: the Power Law Rant,' http://scottbot.net/networks-demystified-3-the-power-law-rant/.
36. Though it offers no absolute standard of what it *means* to be 'central' in a cross-referencing system, data visualization makes it reasonable to raise the question and possible to offer answers. Mark Newman, *Networks: an Introduction* (Oxford: Oxford University Press, 2010), 168–69.

**Table 2. Top twenty headwords by degree centrality**

| Rank | Node (Headword) | Degree |
|---|---|---|
| 1 | Earth | 176 |
| 2 | Air | 165 |
| 3 | Figure | 150 |
| 4 | Measure | 149 |
| 5 | Angle | 147 |
| 6 | Plant | 142 |
| 7 | Fire | 141 |
| 8 | Action | 139 |
| 9 | Planet | 130 |
| 10 | Head | 126 |
| 11 | Generation | 125 |
| 12 | Eye | 122 |
| 13 | Moon | 119 |
| 14 | Motion | 119 |
| 15 | Colour | 118 |
| 16 | Attraction | 117 |
| 17 | Gold | 113 |
| 18 | Order | 113 |
| 19 | Point | 112 |
| 20 | Circle | 110 |

Different degree centrality measurements, then, produce different-looking diagrams and indicate nodes with different kinds of importance within the network. Comparing those measurements, however, reveals that though the terms and totals change, there are compelling consistencies. Nineteen of the terms in table 2 would also appear in the top twenty measured solely by either indegree or outdegree.[37] Chambers moreover includes all nineteen in his Directory, so they can be attached to particular subjects (tab. 3). Several occur under multiple heads, and others have affiliations beyond

37. 'Order' slips to the 21st position in a list ranked by outdegree.

those Chambers records, but these can be assigned by reading what is now a more manageable number of significant entries. The three-column entry 'Head', for instance, explains the place of that term in architecture, gardening, heraldry, navigation, horsemanship, and fortification but treats it first and foremost as anatomical. 'Action' too traffics in many discourses – it first appears in Chambers' Directory under ethics – but the first two words of its actual entry, 'in Physicks', bring it into line with the entries for 'Air', 'Figure', and 'Generation', which begin almost identically. In each case, physics comes first.

Another kind of centrality measurement clarifies prioritized subjects still further. The eigenvector centrality of a node increases with its connections to other well-connected nodes: entries with many cross-references to or from other entries that also have many cross-references have higher scores. This metric identifies an even smaller selection of entries central to Chambers' ordering of knowledge and a potential structural bias within the reference system. 'Earth' remains at the top with the highest eigenvector score, but 'Planet', 'Gravity', 'Sun', and 'Body' now round out the top five. Indeed, twelve of the top 20 are related to celestial mechanics (tab. 4). Readers following the references and attempting (as Chambers says they should) to reconstitute cognitively all the arts and sciences would therefore find a core of strongly interconnected entries devoted to parts of natural philosophy, natural history, and mathematics. This core would itself be, broadly speaking, separate from the terms of subjects such as metaphysics, politics, law, poetry, rhetoric, grammar, and religion. Eigenvector centrality suggests, for example, that despite their near equivalence when measured by simple degree, 'Gravity', in terms of network structure, is more important than 'God'.

**Table 3. Headwords with associated arts and sciences**

| Node (Headword) | Sciences | Arts |
|---|---|---|
| Earth | Minerology | Geography<br>Agriculture |
| Air | Meteorology | Pneumatics |
| Figure | Geometry | Sculpture<br>Heraldry |
| Measure | Geometry<br>Law | Hydrostatics<br>Pneumatics<br>Chronology<br>Poetry |
| Angle | Geometry | |
| Plant | Phytology | |
| Fire | Meteorology | Chymistry |
| Action | Ethics | Commerce<br>Rhetoric<br>Poetry |
| Planet | | Astronomy |
| Head | | Anatomy |
| Generation | Zoology | |
| Eye | | Anatomy |
| Moon | | Astronomy |
| Motion | Statics | |
| Colour | | Manage |
| Attraction | Physics | |
| Gold | Minerology | |
| Point | Geometry | Perspective |
| Circle | Geometry | Astronomy<br>Geography |

**Table 4. Top twenty headwords by Eigenvector centrality**

| Rank | Node (Headword) | Eigenvector Score |
|---|---|---|
| 1 | Earth | 1 |
| 2 | Planet | 0.887752 |
| 3 | Gravity | 0.791207 |
| 4 | Sun | 0.693159 |
| 5 | Air | 0.68103 |
| 6 | Body | 0.662514 |
| 7 | Sphere | 0.633845 |
| 8 | Circle | 0.62923 |
| 9 | Heat | 0.612376 |
| 10 | Fire | 0.594921 |
| 11 | Salt | 0.590671 |
| 12 | Moon | 0.588866 |
| 13 | Motion | 0.564907 |
| 14 | Star | 0.550293 |
| 15 | Centre | 0.541702 |
| 16 | Attraction | 0.531174 |
| 17 | Refraction | 0.522706 |
| 18 | Blood | 0.505383 |
| 19 | Water | 0.474528 |
| 20 | Gold | 0.473391 |

In this respect, Chambers was consistent. He devotes less attention to the cross-referencing of some subjects than others – even those given priority in his Directory. No headword enumerated under the category of metaphysics, for instance, which at number seven in his order precedes mathematics, has more than a total of 100 incoming and outgoing references. This does not mean Chambers found the faculties of reason, memory, and understanding or the concepts of art, science, and knowledge to be of little importance. It rather suggests that the elevated position of metaphysics in his Directory does not necessarily correlate with the integration of its parts with other areas of knowledge production. Towards the end of the preface, he even laments that, like logic, metaphysics has been 'refined to a degree of subtilty that destroys [it].'[38] The disjunction between the structure he offers in his View of Knowledge and that which emerges from the reference system illustrates the diminishing status of metaphysics in the early conceptual shaping of the scientific disciplines with which Chambers was primarily concerned.

## LAYOUT

Having established what some of the nodes are, we can briefly turn our attention to where they are. Gephi uses algorithms to determine different ways of representing the mathematical relationships between and among nodes when projected in a two-dimensional space. A force-directed layout, such as the one used for this analysis, 'simulates a physical system in order to spatialize a network. Nodes repulse each other like charged particles, while edges attract their nodes, like springs. These forces create a movement that converges to a balanced state.'[39] More interconnected nodes tend to be drawn into groups, groups with more connections tend to be drawn towards each other; nodes and groups with fewer connections tend to drift apart. The resulting diagrams are stochastic – there is no 'one true layout' – but visual network analysis can point towards 'hidden' patterns or dynamics to investigate further via more reliable metrics.[40]

The diagram appears to be divided into roughly two parts (see fig. 1). The largest nodes – no matter which metric is used to size them – here cluster in the centre and on the left, while a broad swathe along the right-hand perimeter contains few nodes of similar 'importance' and appears overall to be less densely connected. A closer look indicates that Chambers' blueprints do not match the system he actually built; the reference system creates an order of knowledge perhaps complementary to but certainly

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38. Chambers, *Cyclopaedia*, 1: xxvi.
39. M. Jacomy, T. Venturini, S. Heymann, and M. Bastian, 'ForceAtlas2, a Continuous Graph Layout Algorithm for Handy Network Visualization Designed for the Gephi Software,' *PLOS ONE* 9, no 6 (2014): 2.
40. Ahnert *et al.*, *The Network Turn*, 38, 67–8.

different from the one he imagined in his 'View of Knowledge' diagram and expanded upon in his Directory. Indeed, it seems to connect some arts and sciences that Chambers' View divides and divides others in ways that anticipate an order of knowledge not formally institutionalized until the following century.

Several clusters, often anchored by one or more larger nodes, include obviously related terms. Some even approach what one might be tempted to interpret as identifiable subjects. Nodes in the immediate vicinity of PLANET, for example, include ORBIT, ORB, AXIS, ECLIPSE, ASTROLOGY, ASTRONOMY, and VESPER; POINT, CIRCLE, GLOBE, RING, ALTITUDE, DISTANCE, SPHERE, and STAR surround ANGLE; and HEART sits amid PALPITATION, CIRCULATION, GILLS, EXCREMENT, STOMACH, HYPOGASTRIC, and ANATOMY. As one might expect, EARTH, AIR, FIRE and WATER – the four classical elements and four of the largest nodes in the diagram – likewise appear in close proximity to each other (fig. 3).[41] Nodes amid and around them include, among others, HEAT, MERCURY, MAGNETISM, TIDES, BAROMETER, VEGETATION, and ATMOSPHERE. The size and relative proximity of the 'four elements', as well as the assortment of terms congregating around them, demand additional scrutiny regarding their relation to the rest of the system and the extent to which they captured the contemporaneous development of experimental physics as an area of natural philosophy focused on a particular subset of natural phenomena.[42] The layout suggests that Earth, Air, Water, and Fire, though no longer the ancients' irreducible elements and soon to loom large in separate sciences, remained (in terms of network analysis) central to Enlightenment re-conceptualizations and knowledge of the physical world.[43]

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41. If combined, the cross-references to all entries with the headword WATER would number 131 and so be among the largest nodes in the network when measured by degree.
42. By the 1720s, experimental physics had narrowed 'to include the study of heat, light, electricity, and magnetism and exclude anatomy, medicine, natural history, and chemistry.' Thomas Hankins, *Science and the Enlightenment* (Cambridge: Cambridge University Press, 1985), 49.
43. Fire and air would later become crucial components of the Chemical Revolution; see Hankins, *Science and the Enlightenment*, 81–112.

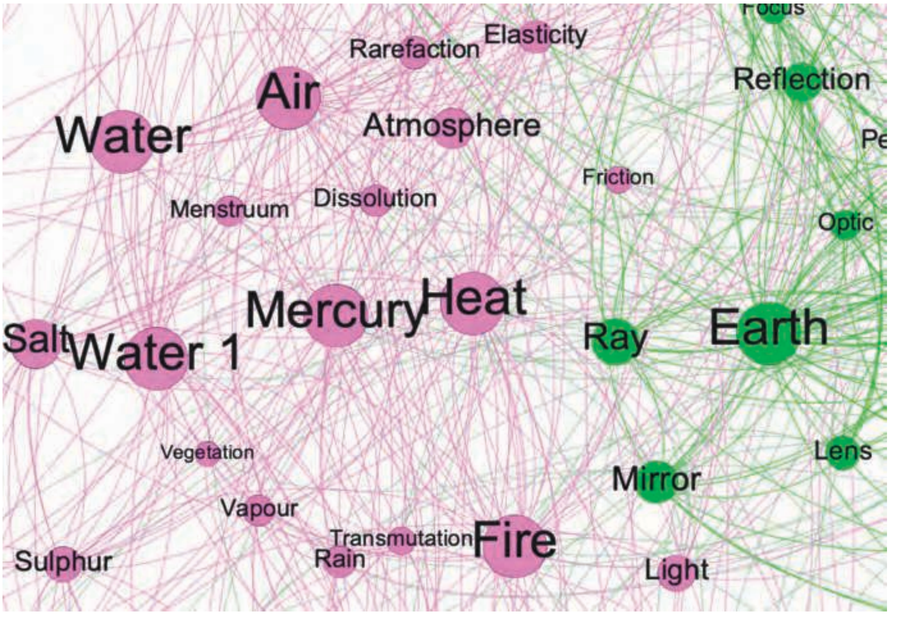


**Fig. 3. The four elements: 'Air', 'Earth', 'Fire', 'Water'**

The 'other side' of the diagram hints at other kinds of epistemic turns as well. ACTION, the fourth largest node by outdegree and the seventh largest overall, offers a clear example of a term attached to different, if not divergent, parts of knowledge. To twenty-first-century readers, the word likely conjures thoughts of physics or legal proceedings. Its apparent importance to the network redirect attention to the text, in which Chambers' Directory first lists it under 'Ethics'. The entry itself prioritizes physics, but only eleven of its 86 outgoing references lead to the 'Laws of Nature', (RE-ACTION), the 'Actions of Powers' (WEIGHT, FRICTION, etc.), or the 'Actions of Fluids' (FLUID, SPECIFIC GRAVITY). By far the largest share of the entry's cross-references connect it to terms associated with grammar, poetics, or law (PRONUNCIATION, CASE, FABLE, EPIC, TRAGEDY, UNITY, CIVIL, ASSIZE, JUSTICE, COURT, etc.) (fig. 4). The same holds true of its 53 incoming references. Only three ('Reaction', 'Attraction', and 'Rocke') belong to any branch of natural philosophy or mixed mathematics, and all 19 of the mutually connected entries – headwords cross-referenced by 'Action' the entries of which refer back to ACTION – again belong to rhetoric, law, or the arts of painting and sculpture. At a moment when a classical education still conferred a great deal of cultural capital and the idea of 'action at a distance' posed a significant obstacle to the acceptance of Newton's theory of gravity, Chambers thoroughly linked 'Action' to poetics and left largely cut it off from or only indirectly connected to astrophysics.[44]

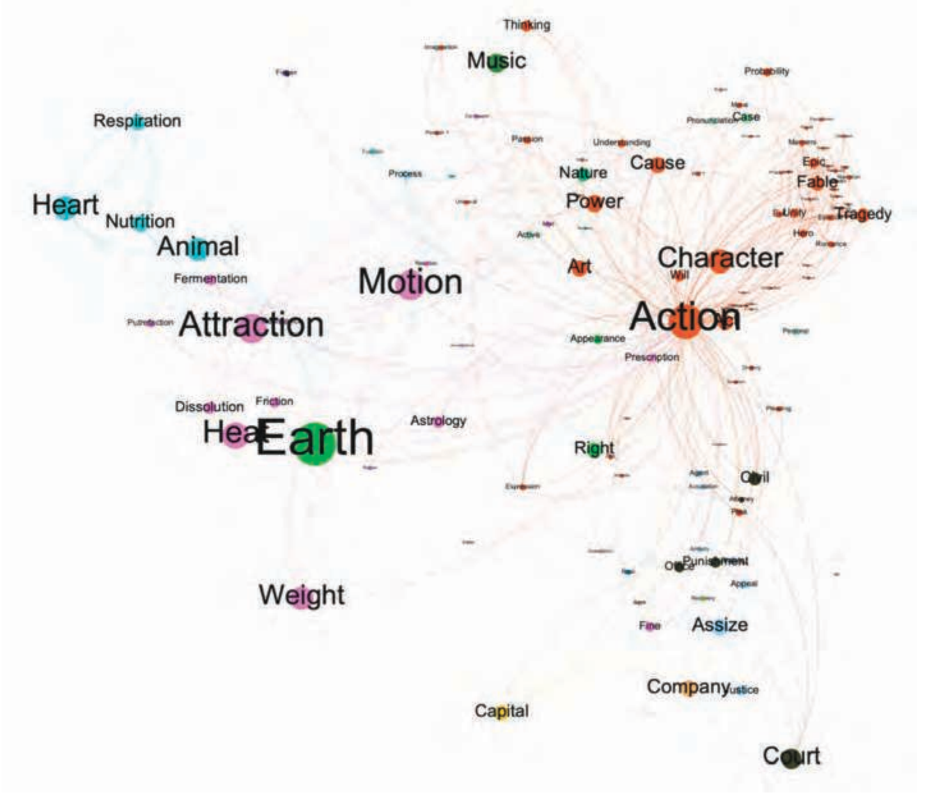


**Fig. 4. 'Action'**

44. 'Action' cross-references neither GRAVITY nor NEWTONIAN. See Andrew Janiak, *Newton as Philosopher* (Cambridge: Cambridge University Press, 2008), 53–7.

The data by themselves would show as much, but setting the whole to view brings such features into the foreground. Visualization can likewise illuminate a significant *lack* of relative importance. The apparent division created by the dearth of very high-degree or high-centrality nodes in so much of the diagram resembles the phenomenon described by Blanchard and Olsen in their study of the *Encyclopédie*. Their analysis of *renvois* showed a vaguely comparable (albeit far more discretely hemispheric) structure:

> The first hemisphere comprehends experimental sciences linked to the observation of nature, such as 'natural history', 'botany', 'chemistry', 'medicine', 'anatomy', and to rural life ('rustic economy', 'agriculture'). The second hemisphere, more important and with a more complex internal structure, includes all the 'abstract' ('mathematics', 'geometry') and speculative ('philosophy') sciences, letters, applied sciences ('mechanical arts'), and the foundations and laws of human society ('history', 'law', 'morality')… One could say that the division as represented separates the domain of the apprehension of nature from that of the intellectual and practical constructions specific to the human mind.[45]

The layout suggests that a similar dynamic may be at work in the *Cyclopaedia*. The assortment of smaller nodes that have tended towards the right of the diagram correlate strongly with subjects Chambers assigned to the rational branch of knowledge related to 'our happiness', the 'symbolical' branch of external knowledge, and certain extensions of the 'real'. The terms of courts and clerkships, aldermen and exchequers constitute Law and Politics, which are in turn branches of Ethics and Natural Religion; ordinaries, abbots, bishops, and benefices make up the Church, which stems from Theology; Pindaric, proposition, epic, ablative, and syntax represent the framing of Words, Figures, and Fables called Grammar, Rhetoric, and Poetry; and columns, plinths, mouldings, and pedestals build up Architecture. These and a myriad others make for a motley collection of terms and subjects that suggest an order of knowledge divided not into the natural and scientific

45. Blanchard and Olsen, 'Le système de renvois,' 61.

or artificial and technical, as Chambers would have it, but rather between those parts of knowledge involving the natural world and those concerned with human culture and society. To the extent this order resembles that in the *Encyclopédie,* the latter may have simply sharpened a line already drawn.

## MODULARITY

Appearances, though, can be deceiving. The layout algorithm inevitably represents some relationships more accurately than others: those among smaller nodes are more likely to be mischaracterized than those among larger and (in some sense) more important ones. Modularity is a mathematical assessment of network structure designed to calculate the strength of its division into communities. The goal of the algorithm in this case is to group nodes based on their relationships; highly connected nodes are more likely to belong to the same community or 'module'.[46] Whereas the layout algorithm might place two nodes relatively far apart, modularity might reveal that they are in fact closely related; it might likewise find that two nodes close together might belong to different communities. Chambers wondered, 'whether it might not be for the more general Interest of Learning to have all the Inclosures and Partitions thrown down, and the whole laid common again.'[47] Whereas Chambers constructed an 'artificial', top-down View of how he believed the parts did or should fit together, modularity analysis repartitions the 'whole laid common' from the ground up; the metric detects communities based on the reference system itself. Despite its limitations, modularity in this case balances ease of use with consistent results and well-formed communities that offer a better insight into the relationships Chambers created but could not himself have seen.[48]

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46. Ken Cherven, *Mastering Gephi Network Visualization* (Birmingham: Packt Publishing, 2015), 189.
47. Chambers, *Cyclopaedia*, 1:vii.
48. Modularity optimization typically has trouble identifying structures below a certain scale, which can make it difficult to determine if one has uncovered single communities or conglomerations of several smaller, undifferentiated ones. The authors of Gephi's optimization algorithm acknowledge that their solution requires further assessment.

A truly encyclopaedic analysis of how, to borrow from Pope, 'system into system runs' would require more time and space than is practical.[49] At its default setting, Gephi detects 2,923 communities. Very few, however, comprise more than a handful of terms. As with nodes of high centrality, the decline in size is rapid. Only 21 modules in the network have more than 100 members, and just five of those comprise above 1,000. The overwhelming majority of 'communities' – 2,419, or 82.7% – have just one node; 526, or 17.9%, have between 2 and 8. A group of 65 is the only one in the range between 9 and 145. Modules with fewer than 400 nodes are visually difficult to discern, while the largest communities stand out visually as well as mathematically: their colours and size dominate diagram and network alike (fig. 5). The correspondence of all these communities with the structure Chambers imagined but could only partially chart not only illuminates eighteenth-century proto-disciplinary dynamics, but may also have anticipated the later division of knowledge into what we would identify as STEM, the social sciences, and the humanities.

Community 1 – the network's largest, with 1,508 nodes shaded pink in the network visualization – contains numerous terms from the first three parts of natural history: meteorology (e.g. SNOW, RAIN, WIND, FROST); hydrology (e.g. SPRING, DELUGE, OCEAN, LAKE); and minerology (e.g. GOLD, SILVER, COPPER, COAL, GLASS). The same community, however, also includes REFINING, MINE, FURNACE, AND FORGING, AND GRINDING. As terms of Trades and Manufactures, Chambers places these on the 'artificial and technical' side of his View under the umbrella of mechanics and mixed mathematics. Modularity, though, has classed them among the objects to which the arts are applied. The same can be said of pharmacy and medicine. DRUG, GUM, and POISON join 300 other nodes in Community 16, a module made up of everything from ANALEPTICKS to COFFEE to NARCOTICS to TEA. A scattering of related terms like PANACEA, ACETUM, and TURBITH are classed

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See Santo Fortunato and Marc Barthélemy, 'Resolution Limit in Community Detection,' *PNAS* 104, no 1 (January 2007): 36; and Vincent D. Blondel, Jean-Loup Guillaume, Renaud Lambiotte, and Etienne Lefebvre, 'Fast unfolding of communities in large networks,' *Journal of Statistical Mechanics: Theory and Experiment* 10 (2008): 2–11.

49. Alexander Pope, *Essay on Man*, in *The Poems of Alexander Pope*, vol. II, ed. John Butt (New Haven: Yale University Press, 1963).

within Community 1, but given what medicines are made of (acetum is a preparation from vinegar, turbith from a species of morning glory), the overlaps and admixtures of these communities make sense. Community 2 – the second largest module, with 1,371 nodes shaded green – testifies to the increasing reach of mathematical analysis and concurrent development of mixed mathematics in the seventeenth and eighteenth centuries.[50] DIALLING, NAVIGATION, PERSPECTIVE, and CHRONOLOGY – four of the six arts enumerated in Chambers' View as constituting astronomy, geography, and optics – are all applications of mathematics, and in the early eighteenth century all were intimately connected to geometry, the parts of which are in the same group. The cross-references in both cases reconnect the sciences and arts that Chambers' order separates and do so precisely as one might expect.

The unexpected, though, can tell us even more about the changing order of eighteenth-century knowledge. One might, for instance, expect to see the eye classed with other body parts or at least within modules strongly correlated with natural history, anatomy, or zoology. Modularity analysis, however, places EYE, along with VISION and SIGHT, in the same community as GEOMETRY, MATHEMATICS, OPTICS, RAY, and PERSPECTIVE (fig. 6). No other sensory organ belongs to this community. According to Wilda Anderson, 'Newton used the theory of colour in light to justify the use of a particular sense, that of vision, as being not inherently subject to error'. To convince the world that empiricism made sure footing for the production of knowledge, sight and certainty had to go hand-in-hand. 'The mathematization of visual data through the *Opticks*', Anderson continues, 'allows them to be used to validate reasoning from sensation, and thus justifies the visual observations and measurements underlying the celestial mechanics.'[51] The Newtonian context thus provides reasons why the eye and an assortment of the anatomical structures connected to it would appear within the modules they do. Knowledge of seeing and knowledge of the seen were mutually constitutive.

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50. J. L. Heilbron, 'A Mathematician's Mutiny, with Morals,' in *World Changes: Thomas Kuhn and the Nature of Science*, ed. Paul Horwich (Cambridge, MA: MIT Press, 1993), 311–341.
51. Wilda Anderson, 'Optics and Illusion of Empiricism in the *Encyclopédie*,' *MLN* 126, no 4 (September 2011): 873–874.

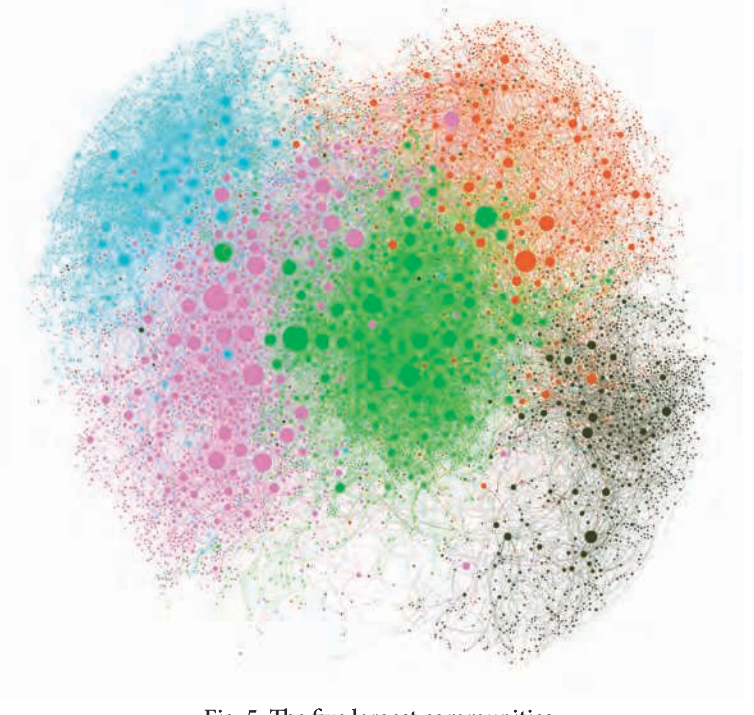

**Fig. 5. The five largest communities**

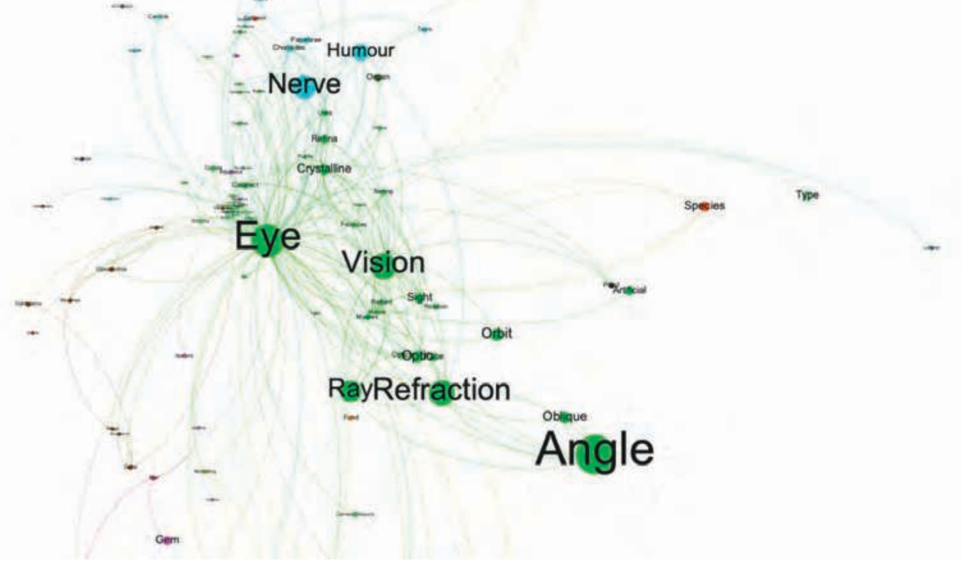


**Fig. 6. 'Eye'**

A casual reader might not perceive that dynamic at work in each entry of the relevant subset. Chambers' six-column entry on 'Eye' primarily consists of brief accounts of its physical components and operation – muscles, nerves, sclera – and several paragraphs devoted to comparative anatomy. The article only gestures towards the mechanics of sight through a brief explanation of rays entering the pupil and being collected by the crystalline, which then 'throws' them upon the retina. It does not deploy the equations or proofs of mathematics, and its cross-references quantitatively and qualitatively support its overall categorization as anatomical or zoological. The entry on 'Vision', in contrast, has a separately titled subsection devoted to 'Modern Theory' that resituates the eye squarely within the body of geometry: 'suppose, e.g. Z, the eye, and ABC the object… Now, tho every Point of an Object be a radiant Point, that is, tho there be Rays reflected from every Point of the Object to every Point of the circumambient Space…'[52] The eye, pupil, and humour described in the entry on 'eye' become subordinate to the universal action of light, and the eye itself appears in the optics plates as a simple geometric line drawing under the word 'vision'. In isolation, 'eye' and the entries it cross-references would have readers see it in the flesh.[53] By accounting for the cross-references in all of those entries, however, modularity analysis indicates the special status of the eye in the early eighteenth century as an object of mathematical as well as anatomical importance. It further affirms the role of the *Cyclopaedia* in the ongoing mathematization of nature at the core of the scientific revolution.

Similar forces are at work on EARTH. The layout places the node in close proximity to the classical elements, but modularity analysis indicates a separation. Unlike WATER, AIR, and FIRE, all of which appear in Community 1, EARTH – the highest-degree node in the network – is in Community 2; modularity has classed it with the other celestial objects of Newton's clockwork universe (see fig. 3). Whereas the substance and outgoing references of 'Eye' seemed in opposition to the findings of this

52. Chambers, *Cyclopaedia*, T. II, 314.
53. This line drawing is the only graphical representation of the eye not in a head; there are no anatomical renderings like those of the veins, bowels, bones, etc.

kind of analysis, those of 'Earth' support them. The entry opens with an acknowledgement of the classical paradigm but immediately attributes the confusion of the 'vulgar' element with the world 'whereon we tread' to an ancient misunderstanding of Aristotle.[54] Subsections in the columns that follow involve chemistry, natural history, agriculture, and gardening, but none match the length of those given to geography and astronomy. The entry primarily covers planetary characteristics long argued about but, in the wake of early modern science, attributable to universal laws governing shape, size, and motion. In Chambers' Directory, 'Earth' means mineralogy. In the entry, and within the network, 'Earth' means *the* Earth.

If the classifications of EYE and EARTH represent two examples of the mathematization of nature, then Communities 3 and 8 may well represent patterns in the prehistory of modern biology. Neither the term nor the discipline existed until the turn of the nineteenth century. In fact, as Thomas Hankins writes, modern philosophers and historians, including Michel Foucault, have argued that 'there could be no science of biology before 1750 because there was no understanding of life separate from the non-living world.'[55] The description and classification of all three kingdoms of nature – animal, vegetable, and mineral – in the first decades of the eighteenth century still took place under the banner of natural history. Chambers labels phytology and zoology as distinct areas of exploration within the larger science, but still as only two in a group of five that, as noted above, included meteorology, hydrology, and mineralogy. His View of Knowledge therefore reflects what in 1728 remained the status quo: early modern approaches to natural history did not distinguish between the animate and inanimate.

Modularity analysis, however, does. The diagram indicates new structures of knowledge in the process of formation. Community 3 (1,191 nodes, shaded blue) comprehends hundreds of body parts and processes along with a smattering of physical ailments. The three nodes of highest degree centrality are HEART, CIRCULATION, and BLOOD; other major nodes include MUSCLE, NERVE, BRAIN, DIGESTION, RESPIRATION, and EXCREMENT. The most

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54. Chambers, *Cyclopaedia*, 262.
55. Hankins, *Science and the Enlightenment*, 117.

important nodes of Community 8 (701 nodes, shaded red) are PLANT, SEED, and FLOWER, though its membership also extends to the associated arts represented by AGRICULTURE and GARDENING (fig. 7). The measurement, as is to be expected, returns imperfect results; nodes that clearly belong to zoology appear in Community 8 (FOETUS, ANIMALCULA, PREGNANCY) and some of phytology show up Community 3 (BARK, CINNAMON, SPICE). GENERATION and LIFE, two terms that very much belong to both, tip into the plant and animal worlds, respectively. The boundaries between them are messy, then, but still generally discernible via mathematical analysis – not only from each other, but also and more significantly from the rest of natural history. Though similarly inexact (particularly at the level of nodes with few connections), the diagram suggests an approximate boundary separating meteorology, hydrology, and mineralogy in the natural history community from the other two subfields: phytology and zoology, which appear mainly in Communities 3 and 8, respectively.

It does not, moreover, detect such boundaries amongst the first three. STONE anchors a small community of 256 nodes that roughly overlaps with the delineated subsections of stones, gems, and petrifactions at the end of the breakdown of mineralogy in Chambers' Directory, but the bulk of the science nonetheless remains in Community 1 along with everything from OCEAN, RIVER, and RAIN to COLD, CONDENSATION, and VACUUM. The inanimate elements of natural history, in other words, belong in the main to one large community while the best part of life has taken root elsewhere. The separation does not contradict the larger historical record of disciplinary development and institutionalization; biology does not emerge in or from the reference system of the *Cyclopaedia* as a formally delineated field of study. Modularity analysis, though, reveals a fault line in the larger body of scientific knowledge that anticipated the need for those specialized approaches that would in later decades give rise to a new discipline.

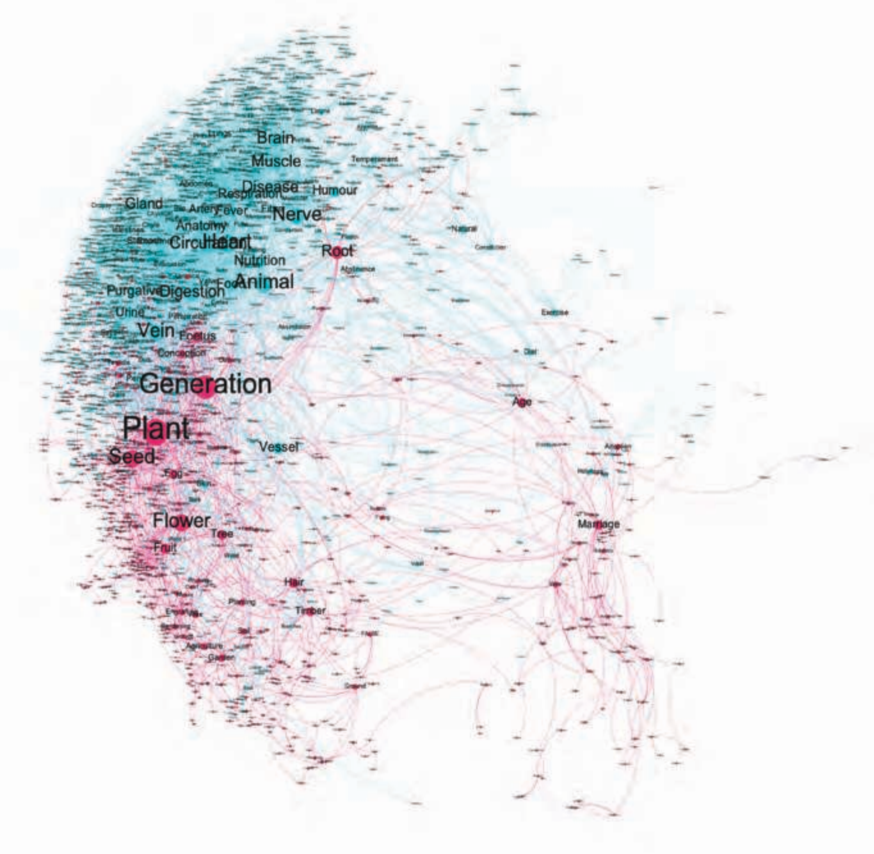


**Fig. 7. Communities 3 and 8**

In contrast, a selection of the smaller communities in the top 20 correlate closely with subjects that eighteenth-century readers would have found reasonably coherent. In addition to pharmacy and medicine are some we would now class as Fine Arts – a category incipient in the eighteenth century but that does not appear in Chambers' Directory.[56] Community 13, for example, contains 406 nodes (shaded dark green) that distinguish music from the field of mixed mathematics from which Chambers derives it. Terms of architecture and sculpture similarly account for most of the 736 nodes

56. Larry Shiner, *The Invention of Art: a Cultural History* (Chicago: University of Chicago Press, 2001).

in Community 6 (shaded in gold, toward the bottom of the visualization). To be sure, modularity does not discern all the applications of astronomy, geography, or optics enumerated in Chambers' view, and not all the divisions it detects align perfectly with modern orders of knowledge. Nodes representative of visual arts such as painting, drawing, and mosaic, for example, remain classed with generic natural history in Community 1, and where we might expect divisions between sculpture and architecture or between music and dance, both sets of terms are grouped together. The fact that some community structures detected mathematically match Chambers' View more nearly than others directs critical attention to the apparent deviations.

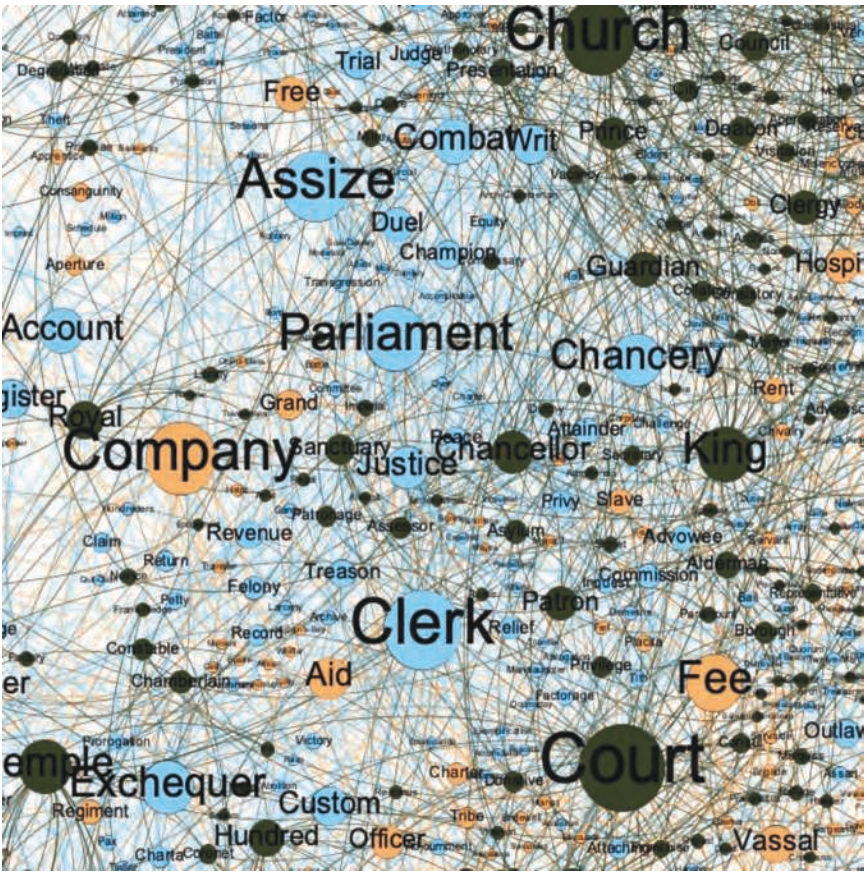


Fig. 8. Doctrine of Offices

Despite his having delineated their wholes and parts no less clearly than those of any other subjects in his View and Directory, modularity analysis indicates that the boundaries among poetry, rhetoric, law, politics, and religion are perhaps the most porous in the network. The 1,153 nodes of Community 4 (shaded orange), albeit predominantly made up of the first two, contains elements of all of them, along with a myriad ontological and epistemological terms that Chambers lists under metaphysics.[57] The nodes of Communities 7 and 10 (shaded pale blue and light orange, respectively, and sweeping up across through the lower right quadrant), meanwhile, belong largely to church and state: PARLIAMENT, CHANCERY, HOUSEHOLD, DUTY, and DISTRESS mix ARMY, ADMIRAL, ALMS, TAX, TENANT and FEE as well as COURT, GUARDIAN, and CHURCH. The latter three belong to the same community as ATTORNEY, PRIEST, PUNISHMENT, and EMPIRE – Community 5, comprehending 1,063 nodes with no discernible predominating subcategory. Adjusting the algorithm to find fewer communities resolves these three into a single representative of what Chambers calls the Doctrine of Offices, but comparing its parts to other communities detected at the same initial resolution reveals the relative chaos of socio-political structures and the substance of intellectual activity insofar as Chambers managed to systematize them (fig. 8).

It seems, then, that most of the largest single groups, whether rational or artificial, align more closely with what modern readers would consider 'hard' scientific or STEM subjects, while the rest make up the objects and institutions of what we now know as the social sciences and humanities. The layout algorithm, furthermore, appears to have pulled the three groups apart from each other. The actual extent of their separation, though, can also be measured. In network topology, the shortest path length is the fewest number of steps one must take to get from one node to another. In terms of the reference system, it represents the fewest number of entries through which a reader would have to pass by following the cross-references to get from one entry to

57. They have many words in common: characters (heroes and plus signs), rules (unities and operations), and abstracts (abridgements, ideas, and 'pure' as opposed to applied mathematics).

any other. Calculating the average shortest path length between all the nodes of one module to all the nodes of another gives the average shortest path lengths between and among entire communities. Assuming that a shorter average path indicates closer communities (an assumption borne out by the fact that all of the communities are closest to themselves) and allowing that community size can affect distance, such measurements can put numbers to the relative distances between different parts of the network.

Those numbers broadly support the tripartite division, particularly among modules of similar size. Among the five largest – those with more than 1,000 nodes – Community 3 (anatomical parts and processes) is closest to Community 1 (natural history): the shortest average path length from the nodes of one to the other is 6.27. The distances from Communities 3 and 1 to Community 5 (ethics, law, religion), in contrast, are 7.34 and 6.9, respectively. Natural history's closest neighbouring community is 2 (mathematics, various mixed mathematics), with an average path length of 5.79; Community 2, in turn, is also most distant from Community 5, at 6.8. Even Community 4, for all its terms of poetry and rhetoric, is further from Community 5 than any of the other three. Path lengths between midsize communities (between 400–800 nodes) follow a similar pattern. Those comprising music and grammar, for example, are closer to each other than either is to pharmacy or minerology, but the path lengths between the latter and the former are almost the same as those between the former and the those comprehending additional terms of law and policy.

The numerical differences may seem small, but they are significant and reveal a discernible trend. The view of knowledge that emerges from the reference system is not the one Chambers imagined. Whether reflective of his own priorities, the areas of knowledge with which he was most familiar, or a lack of understanding how, where, and when to forge connections that would truly unite the whole, the structures discernible within the network hint at a shift in the order of knowledge underway but not yet complete.

## THE END OF THE BEGINNING

If in one sense the diagramming and analysis of the reference system complete Chambers' vision, then in another they leave the work of and on the *Cyclopaedia* even further away from finished. If, as Dan Rosenberg has argued, the analytic goal of data visualization is 'to complicate rather than simplify, to open multiple avenues of inquiry, and, most importantly, to challenge the stability of underlying data, in fact or in principle', then the relationships between its parts and wholes require additional exploration and analysis.[58] Students of law might further interrogate the network complexity of the Doctrine of Offices; religious historians might consider why Chambers connected HOMUNCIONISTS to the network but marooned MUGGLETONIANS on an island. Those interested in optics might focus on the fact that COLOUR, BODY, and LIGHT do not belong to the same module as REFRACTION, RAY, and PRISM, and literary scholars could consider why the entry on 'Epic' has nearly twice as many references as 'Ode', and 'Ode' five times as many as 'Lyric'. Visualization allows more of the system to meet the eye; more eyes are therefore needed to explain all there is to see.

The spaces between these and other subjects in the diagrams – spaces often absent from Chambers' view and perhaps from his understanding – may be interpreted as evidence of his model's inaccuracies. They may also point to truly unbridgeable gaps between different parts of knowledge or to the need for new approaches that might unite them. Comparing the reference systems of subsequent encyclopaedias, as well as additional single projects or large corpora that in other ways record similar information, might provide a more detailed and dynamic picture of how organizational structures and models have shifted over time and across the globe: a meander map of human learning.

Chambers understood that the order of the *Cyclopaedia* would have to change with our understanding of the order of the universe. Visualizations likewise require review and revision: to be plotted, modified, and seen

58. Daniel Rosenberg, 'Against infographics,' *Art Journal* 75 (2016).

again. The images above are neither the only, nor necessarily, the best of all possible diagrams; the sense they help make of an otherwise overwhelming amount of information, though, represents a step towards the fulfilment of the quintessentially Enlightenment idea that sense can ultimately be made of it all – that we can see our way to a more complete understanding of the vast and evolving encyclopaedic project.