
1. APPROACHES TO SPINOZA

One of the most remarkable features of the *Ethics* is its axiomatic form. Spinoza sets out at the start a small number of definitions and axioms that are assuredly true, and proceeds to deduce from these the rest of his philosophy. In this respect, the work is an attempt to use a theory of philosophy that is modelled upon Euclid's *Elements*. Historically, the axiomatic form had a long tradition; direct influence upon Spinoza has been attributed amongst others to Descartes, Hobbes and Geulincx [7, p. 169]. But the *Ethics* is significant in that it is the only major philosophical work of the 17th century rationalists which undertakes, and at least in form achieves, the frequently expressed goal of extending the mathematical method in this direction." [9, p. 16]

What should we make of the use of axiomatic form? In 1834, Heine wrote:

Dann finden wir bei Spinoza, wie bei Descartes, die der Mathematic abgeborgte Beweisführung. Dieses ist in großes Gebrechen. Die mathematische Form gibt dem Spinoza ein herbes Äußere. Aber dieses ist wie die herbe Schale der Mandel; der Kern ist um so erfreulicher.

(Then we find in Spinoza's work, as in Descartes, proofs backed up by mathematics. This is a great crime. Mathematical form gives Spinoza a bitter/unpalatable surface. But this is like the bitter shell of an almond. The kernel itself is all the more pleasurable for it.)

The notion that the axiomatic form makes Spinoza difficult to approach is a common one; so too is the notion that there is the real philosophy of Spinoza hidden inside, struggling to get out (see, eg. [13, p. xi]). This view reaches its most extreme form in Wolfson [6], who describes the axiomatic method as a purely literary mode of presentation which has little to do with the actual philosophy. As a mode of presentation it might have several ends: a greater clarity (although the bafflement with which it is often met suggests a lack of success in this respect); authority and prestige through association with Greek mathematics [10, p. 270]; the guarantee of correctness through the use of deduction; or the ability to compel readers [7, p. 144].

An alternative view is that the axiomatic form is a necessary part of Spinoza's *Ethics*: that the work would be inexpressible in any other form; or that its layout was chosen to reflect the mathematical order of nature in that causes always precede effects [10, p. 266]; or that, since Spinoza had concluded that reason (*ratio*) and intuition (*scientia intuitiva*)—these being the second and third kinds of knowledge—were the routes to true knowledge [II, prop. 41], and since intuition could not be conveyed in a book [7, p. 164], it would be absurd for him to use any form other than reason. (And this *ratio* is by definition axiomatic: for argument-by-example, and unordered argument, are part of the first kind of knowledge [II, note 2 to prop. 40]).

A second remarkable property of Spinoza's axiomatic form is the fundamental disagreement among interpreters concerning practically every aspect of this method" [12, p. 55]. Nothing written in the previous paragraphs is uncontroversial. Is the form axiomatic, geometric or mathematical [10, p. 264]? Is it a form (*synthetic*, referring to the manner in which knowledge is laid out), or a method (*analytic*, referring to the manner in which knowledge is gained) [7, p. 153]? Are Spinoza's definitions and axioms assuredly true [10, p. 273]? Is there a fluid boundary between axioms and propositions [13, p. 157]? The extent of disagreement between interpretations, says Jarrett, inclines one to suspect that no interpreter can cast off the biases of his own outlook, in order to give a relatively objective interpretation of Spinoza" [9, p. 16]

In this essay we present the results of computer-based quantitative analysis of the structure of the whole of Spinoza's *Ethics*. This is done with two ends. First, we use quantitative techniques as an aid to textual investigation: the computer can point out particular interesting features of propositions that might otherwise go unnoticed. Second, a statistical analysis of the entire structure will provide objective data about overall structural and thematic patterns. This may provide a little additional evidence for some of the aforementioned controversies.

2. METHOD AND NOTATION

The source used in this study was the Latin text in the 1977 edition of *Ethique* [4], arranged by the French Spinoza Committee.

Most proofs make explicit reference to the earlier theorems upon which they depend: for instance, consider the proof for p5.4:

Quæ omnibus communia sunt, non possunt concipi nisi adæquate (per Prop. 38 p. II); adeoque (per Prop. 12 et Lemma 2, quod habetur post Schol. Prop. 13 p. II) nulla est Corporis affectio, cujus aliquem clarum et distinctum non possumus formare conceptum. Q.E.D.

(That which is common to all things can only be adequately conceived (by II, prop. 38); and so (II, prop. 12, and Lemma 2 which is after II, prop. 13) there is no affection of the body of which we cannot form a clear and distinct conception.)

This can be represented diagrammatically with lines drawn from p2.38, p2.12 and lemma2.2 to p5.4 (see Fig. 1). In this essay, terminology is as follows. We say that the first three are referenced, or *cited* by p5.4; since there are three references, we say that p5.4 has an *in-degree* of three. It happens that p5.4 is cited three times (by p5.4c, p5.14 and p5.20n): we say that it has an *out-degree* of three. We have created a database which lists all references made by every proposition. This database has been analysed to calculate such facts as (for instance) the citation score for each proposition: the various tests performed and their results will be presented through the essay. We reflect upon the suitability of this form of measurement in the concluding sections of this essay.

The body text (excluding title and contents) of the Ethics may be divided up into the following categories:

Part of text	Example
Prefaces	Preface to Part II
Definitions	d1.1
Explanations of definitions	after d1.6
Axioms	a1.1
Postulates	Postulate 1 before p2.14
Propositions	p1.1
Proofs of propositions, corollaries and lemmas	after p1.1
Corollaries including proofs	p1.8c
Corollaries with proofs following	p3.40cc
Lemmas	lemma 1 after p2.13n
Notes	p1.8nn
Notes with definitions	p2.40nn
Appendices	Appendix of Part I

Each entry in the database of references was either a definition, an axiom, a proposition, a corollary or a note. Where a definition had an explanation that made references, these were taken as references of the definition. Postulates were treated as axioms, and lemmas were treated as propositions. Appendices and prefaces were ignored.

Where corollaries start with *hinc* (thus) or similar construction, it was assumed that they are making references to the preceding proposition (eg. p1.13c is taken to make a reference to p1.13). Other cases are more ambiguous: consider p3.53 and its corollary.

Propositio LII

Cum Mens, se ipsam, suamque agendi potentiam contemplatur, lætatur; et eo magis, quo se suamque agendi potentiam distinctius imaginatur.

(When the mind considers itself and its power of acting, it has pleasure; and more so when it more distinctly considers itself acting.)

Corollarium

Hæc Lætitia magis magisque fovetur, quo magis homo se ab aliis laudari imaginatur, ...

(This pleasure is more anre more fostered, the more a man imagines himself to be praised by others. For the more he imagines himself to be praised by others, ...)

In cases such as these there is no clear use of the preceding proposition, either by the use of the word *hinc* or by a similar use of words. In cases such as this the database entry for p3.53c does not contain a reference to p3.53. That is, the database of references only stores those references that are explicit.

The database is stored in plain text format; the programs for analysis of it are written in Microsoft Qbasic and can be run on any DOS or Windows machine. The database, programs and results are available by request from the author.

3. IMPORTANT THEOREMS

Mueller writes of Euclid's *Elements* that "almost the entire content of book I can be explained by reference to the construction of a parallelogram in a given angle and equal to a given rectilinear figure in proposition 45" [1, p. 16]. A natural question to ask is: are there any theorems of equivalent importance in the *Ethics*?

Importance is a term with several different meanings: it might refer to the crucial corner-stones of either a section or the entire work; it might refer to the key propositions developed within a section that are used by the rest of the work; or, as in Mueller's case, it might refer just to key propositions irrespective of how they are used later. We will present various metrics primarily with reference to Book I.

An 'crucial corner-stone' might be defined as an individual proposition the removal of which would cause maximum upset to the rest of the section or work. We call this degree of upset the *significance* of the proposition and measure it by summing first those theorems directly affected, and then those indirectly affected, and so on along the chain of deduction. Considering just the impact upon propositions and corollaries in Book I, definitions 3-6 each affect between 75% and 85% of them; axioms 1,4,5 and 7 and propositions 1-7 and 10 each affect between 65% and 75%. Essentially, this means that it would be wrong to single out a particular definition, axiom or proposition as being especially significant within Book I: instead we should conclude that (with the exception of definitions 2 and 7 and axioms 2, 3 and 6) the first few pages of the *Ethics* represent a tightly coupled and undivisible argument.

Looking at the effect not just upon Book I but upon the entire work, the interesting result emerges that a1.4 (The knowledge of effect depends on the knowledge of cause, and involves the same) has influence over some 88% of the propositions and corollaries overall; then come definitions 3, 4 and 6 (of substance, attributes and God respectively) with just slightly lower percentages¹. That axiom 4 is the single most crucial part of all of the *Ethics* perhaps adds a little extra weight to the claim of Fischer (disputed by Mark [10, p. 266]) that the knowledge of nature presented by Spinoza must necessarily mirror in its order the patterns of causality in Nature.

A similar 'crucial corner-stone' analysis of Book II with respect to the entire work presents p2.7 (The order and connection of ideas is the same as the order and connection of things) as the most significant, influencing 64% of the entire work². That this numerical assessment agrees with Friedman's claim that p2.7 is the "central thesis" of Book II [11, p. 80] suggests that the measurement technique has some validity. Similarly, p3.7 at 43% (The endeavour wherewith a thing endeavours to persist in its being is nothing else than the actual essence of that thing); p4.8, p4.21, p4.22, p4.30 at 12%; and p5.21-23 each at 4%. What we have done here is to alert a reader to the fact that these propositions are in some sense the crucial ones in each section; detailed analysis of the significance of each proposition is beyond the scope of this essay.

A second metric that corresponds more closely with Mueller's approach is to measure the *difficulty* of each proposition. We define the difficulty of a proposition as the total number of earlier theorems that must have been established, right from the very beginning, to arrive at that proposition: that is, effectively the amount of work that has gone into proving the proposition. The calculation performed is exactly the same as that for significance but in reverse. (That is, we sum first those propositions directly referenced, then those indirectly referenced, and so on.) In Book I, propositions 28 and 32 are the most difficult, requiring respectively 72% and 65% of the rest of Book I to prove them. In the text overall, p4.73, p5.20, p4.50 and p4.46 are the most difficult propositions, each requiring familiarity with some 60% of the *Ethics*.

The numerical technique of difficulty-analysis has drawn our attention to these propositions, but it does not give us adequate information for analysing their role. Consider for instance p1.32, that Will can only be called a necessary cause, not a free one. "It has taken most of Book I to establish this proposition; and this is the

¹A frivolous application of this result is in evaluation the claim that Spinoza's concept of God "serves as the foundation for the subsequent deductive construction of the entire philosophical system" [7, p. 167]? No, only for four-fifths of it!

²Note that the percentage of influences decreases as we progress, simply because a proposition in Book II cannot influence Book I.

only time that the second half of definition d1.7, of necessary (*necessaria*) things, is ever used in the entire work. Moreover, p1.32 and its corollaries are themselves never used again. The implication of this is stark: Spinoza could have removed p1.32 and the second half of d1.7 without any effect at all on his geometrical order. The proposition p1.32 has no role in his further arguments, and is included purely on its own merits and those of its corollaries. This underlines the importance in Spinoza's system of free will in relation to God; see [12]. In effect, a numerical study of the form of the *Ethics* has given us clues about the content of Spinoza's thoughts.

A final metric of importance is to combine measures of both significance and difficulty. In doing this we hope to identify propositions that are important to the work as a whole, and that have had a lot of work go into them. The significant propositions and corollaries in Book I are identified and a graph is drawn of their deductive relations (see Fig. 2). Alongside each proposition is indicated its significance with respect to Books II to V³. No proposition has much greater significance than all of its descendents: this shows that no proposition has dramatic significance not shared by its descendents. The figure suggests that the important propositions in Book I are 23, 28, 29, 35 and 36. While Mueller showed that the structure of Book I of the *Elements* can be explained with reference to the construction of a parallelogram in proposition 45, we have shown that there is no equivalent proposition in Book I of the *Ethics* that has a corresponding dominance.

4. TIGHT COUPLING

A second area where numerical analysis could shed light is in identifying theorems that are always used together. This would indicate perhaps that one could only be properly understood with respect to another. We will say that two theorems X and Y are *tightly coupled* if, in most places where X is referred to, so is Y. We counted, for every theorem in the *Ethics*, how many times it was used in the same proof as every other theorem.

One particular result is that whenever p5.15 is used (in p5.16, p5.20n and p5.39), so is p5.14; and *vice versa*. The numerical analysis has drawn our attention to this pair of propositions, as an indication that perhaps they should be investigated. (Other tight couplings are indicated in the table; but their investigation is beyond the scope of this essay).

Prop. XI. Quo imago aliqua ad plures res refertur, eo frequentior est seu sæpius viget, et Mentem magis occupat.

Prop. XVI. Hic erga Deum Amor Mentem maxime occupare debet.

Demonstratio. Est enim hic Amor junctus omnibus Corporis affectionibus (per Prop. 14 hujus), quibus omnibus fovetur (per

Prop. 15 hujus); atque adeo (per Prop. 11 hujus) Mentem maxime occupare debet. Q.E.D.

It appears that in the proof of p5.16, the reference to p5.15 is unnecessary. This is because it had already been shown that the love towards God is associated with all the modifications of the body; and p5.11 only requires that an idea have many associations and not that it also be cherished.

It might be suggested that the use of p5.15 to show that the love of God is cherished is an attempt to 'short-cut' the reference to p5.11: that is, to use parts of the proof of p5.11 directly (since they also mention cherishing) rather than using them indirectly through the statement of the proposition.

However, the fact that p5.14 and p5.15 are always paired indicates that their conjunction is not a sign of an attempt to short-cut the geometrical method. Rather, it is indicative of Spinoza's intuition (*scientia intuitiva*) that God-intoxication (p5.14), and self-knowledge and the love of God (p5.15) are intimately bound together.

In fairness, such a conclusion would be a rather strong one to make purely on the basis of a coincidence of propositions and a suspicious proof. But arriving at the conclusion has not been the aim in this section. Rather, the aim has been to illustrate how information on tightly-coupled propositions can be interpreted; and to illustrate the fact that the *shape* of the deductive structure itself has its own story to tell about Spinoza's thoughts and attitudes.

³We do not need to include a measure of significance in Book I, since this information is to some extent already communicated in the graph.

5. PARALLEL TRACKS

There appear to be two parallel tracks running through the *Ethics* [7, p. 161]. The first is a formal, geometrical (and perhaps impenetrable) progression of definitions, axioms, propositions and corollaries; the second is a less structured, more relaxed set of explanations, prefaces, appendices and notes. The second track contains signposts to show what has been covered and what will be proved, and sympathetically holds the reader's hand, as in p2.11n:

Here doubtless the readers will become confused and will recollect many things which will bring them to a stand-still; and therefore I pray them to proceed gently with me and form no judgement concerning these things until they have read all.

And again in p4.18n, after outlining his plans for the next few propositions:

These are the dictates of reason which I purposed in these few words to point out before I proceed to prove them in greater detail.

Steenbakkens writes that, from Spinoza's own point of view, then, the scholia are asides, standing outside the framework of the geometrical exposition" [7, p. 158]. De Dijn notes that "apart from the Scholia and Appendices, [Spinoza] explicitly intends to engage in real demonstration of truths" [12, p. 66]. However, consider the following extract from the proof of p3.18:

As long as a man is affected by the image of anything, he regards the thing as present, although it may not exist (p2.17, p2.17c), nor will he regard it as past or future save in so far as its image is connected with the image of time past or future (p2.44n).

Here (as in many other places) notes are used as part of the formal reasoning in proofs. Consider also the proof of p2.31c:

... and this is what must be understood by the contingency of things and their liability to corruption (*vide* p1.33n).

In this case the reference to the note is not part of the formal proof; rather, it is an aid to the understanding of the reader. That is, in this case the proof itself has acquired the relaxed explanatory nature of a note.

There is in some places an unusual uses of notes. In parts of Books II and III, definitions appear inside the notes. For example, see p2.40nn (definitions for the different types of knowledge), p3.11n (definitions of the basic types of emotion) and p3.30n (honour, shame, repentance). These definitions are generally used and referred to in the same way as are ordinary definitions, with explicit references (see for example p3.37). The cases where this happens in Book III are mirrored in the definitions of the 68 emotions, where for example the explanations of the definitions for honour and shame (d3.30, d3.31) refer the reader back to the note p3.30n in which they were first introduced.

So in some cases notes take on the role of propositions, and propositions take on the role of notes; and in other cases notes become definitions and definitions become notes! In this section we use numerical techniques to compare and contrast notes with propositions.

All the theorems in the *Ethics* were characterised according to whether they are axioms, definitions, propositions, corollaries or notes. A link is said to go from X to Y if X is used in the proof or explanation of Y. Links were tallied up for every proof and explanation, according to the type of statement at either end. To avoid having the results distorted by the unusual use of notes in Books II and III we have taken two measures: firstly by deeming the notes-that-define to be explicit definitions; secondly by ignoring all explanations of definitions. See Fig. 3 for the results.

Figs. 3a and 3b show stylistic differences between propositions and notes. From Fig. 3a we see that propositions are cited more frequently: normally once, occasionally very many times. Notes are generally not cited: this indicates that their role primarily one of explanation rather than argument. Fig. 3b shows that propositions tend to have more hypotheses: two, three or four are typical. (In a pure mathematical deductive system, no theorem would have less than two hypotheses since nothing could be deduced from less). Notes typically have very few hypotheses: they speak in general terms rather than specific.

Figs. 3c and 3d both illustrate that, to some small extent, notes tend to keep to themselves: the likelihood that a note will link to another note is higher than the likelihood that a proposition would link to another note. But they also show that, of those notes that are connected, there are more connections between notes and propositions than there are just between notes. Two influences are at work. First, notes refer to propositions: that is, they do not constitute a parallel stream of argument but rather comment upon or add to what has been written geometrically. Second, propositions refer to notes: once a thing has been incorporated in the text, the

subsequent reasoning can (and does) draw upon them to produce legitimate demonstrations”whatever the thing is [7, p. 161].

The two conclusions outlined above appear superficially to be in conflict; however, they can be resolved with the observation that most notes are not part of the geometric order of argument, and exist primarily as commentary. But of those notes that do participate in the argument, we can say that they participate fully. There is no parallel track in the *Ethics*: notes are inextricably tied to the geometric argument, sometimes in the role of commentary and sometimes as part of it.

6. HIDDEN ASSUMPTIONS

To perform the numerical analyses in this essay, we have constructed diagrams of the explicit references between theorems. This raises an important methodological concern: should we have considered implicit references? There may be implicit references either to implicit axioms (that is, those axioms which are required but not stated anywhere); and there may be implicit references to theorems laid out explicitly earlier in the work.

How large is the domain of discourse? Each proposition in the *Elements* had a finite domain of discourse, limited purely to the set of points, lines and areas in the corresponding diagram. In some sense the domain of discourse of the *Ethics* must also be finite: for, in the thirty-six propositions in Book I, Spinoza is simply unable to talk about more than a few hundred things. In another sense the domain of discourse is unbounded, for Spinoza is using general language to talk about Nature. The precise concern is this: if it turns out that Spinoza uses very many implicit axioms, then a study of purely the explicit theorems would cover only a small part of his work.

Friedman claims to have used 165 extra axioms in his formalization of Book I, but that only 32 of these were not logically necessary; and that he believes that this number can be considerably reduced [11, footnote 3]. Jarrett has presented a mathematical formalisation of Book I using just 15 extra axioms [9, p. 51]; and most of these would be uncontroversial. (For instance, (A9) states that all substances have at least one attribute). This seems a relatively small number of implicit axioms: we conclude that a survey that includes only explicit theorems is not inadequate in this respect.

The second problem concerns implicit references. Netz describes [2, ch. 4] how in Euclid’s *Elements* all references are made implicitly through the use of *formulae* (that is, a previous theorem is evoked through the use of its characteristic syntactic construction). However, not that the Euclid with which Spinoza was familiar was a version in which all references had been annotated [7, p. 140].

One obvious candidate for inspection is a1.2 (That which cannot be conceived through another thing must be conceived through itself), because it is never explicitly cited. Meyers writes in his Preface to

Principles of Philosophy: these things [definitions, postulates and axioms] must be laid down at the start, as a stable foundation on which to build the whole edifice of human knowledge”[quoted in 13, p. 151]. If the axiom was never used then it would be superfluous as regards the rest of the book; and since by design it is self-evident, there is presumably no point in stating it.

Jarrett claims that this axiom should be treated as a bi-directional (That which can be conceived through itself cannot be conceived through another thing, in addition); that it is used implicitly in p2.6, and that it permits a stronger form of d1.3. Moreover, in his formal mathematical version of Spinoza’s proofs, he requires the axiom to prove p1.2, p1.6c, p1.10, p1.11, p1.30 and p1.31.

Two questions remain to be answered on this matter. First, how many implicit references are there? Is a1.2 typical or exceptional? Second, did Spinoza realise that he was implicitly using a1.2? If he did not, then all the analyses in this essay remain valid: the various measurements of significance or difficulty or tight-coupling may not correspond to some putative correct version of the *Ethics*, but they do relate to Spinoza’s conception of his work.

7. STYLOMETRY OF STRUCTURE

We are conscious that statistical measurement of the shape of deductive structure is an unconventional approach to the analysis of historical texts. It seems appropriate therefore to conclude with some general methodological discussion.

In some respects, the analyses in this essay are similar to conventional *stylometric* testing. Holmes describes the method succinctly [17, p. 87]:

The statistical analysis of a literary text can be justified by the need to apply an objective methodology to works which for a long time may have received only impressionistic and subjective treatment. Hesitation by literary scholars and mistrust of such a blatantly quantitative approach may be alleviated by choosing the least contestable mode of analysis, namely that of counting. The stylometrist therefore looks for a unit of counting which translates accurately the "style" of the text, where we may define "style" as a set of measurable patterns which may be unique to an author.

As indicated, there is a great deal of mistrust. It has been suggested that there can be *no* proper relationship between a literary scholar and a stylometrician"[15, p. 244] because literary scholars can never know enough statistics to trust the results. But even between stylometricians there is significant controversy see eg. [16, p. 254; 22, p. 58]. A major concern is that experiments based upon a *selected* subset of tests are suspect, because the experimenter may choose a biased set of tests in knowledge of the material and expected results.

However, there are notable differences between the methods used in this essay and conventional stylometry. First, we primarily use statistical tests to suggest avenues for investigation and do not expect any form of 'yes/no' answer with respect to authorship. Second, the tests performed in this essay were complete: there is no aspect of the geometric order or the links between propositions that was not captured within our database. Third, and most significantly, the order that we are measuring is an order that was carefully and consciously planned by Spinoza, rather than some accidental property such as the number of occurrences of the letter 'è'. In these respects our essay is modelled upon the paper Some Approaches to Computer Analysis of Dialogue in Theater: Buero Vallejo's *En la ardiente oscuridad* in which Irizarry measures statistical properties of dialog between characters to deepen her understanding of the author's intentions.

In this essay we have suggested that a statistical approach can help to deepen one's understanding of the *Ethics*. Various approaches have presented to determine which are the key propositions in Book I; tests of tightly-coupled propositions were introduced, and the close relationship between p5.14 and p5.15 was examined by way of example; and we presented quantitative evidence to suggest that the notes in the text should not be considered a parallel track.

In effect, we have indicated how the detailed shape of the structure of the argument itself has a story to tell; and through numerical analysis we have indicated how the story might be heard.

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