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Measurement and Scales in Aristotle

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MEASUREMENT AND SCALES IN ARISTOTLE

This paper aims to show that Aristotle's treatise on measurement can be seen as the first text handed down to us in Western tradition in which a difference of scales is explicitly discussed. Aristotle divides all magnitudes we can measure into two kinds: magnitudes that require units indivisible in quantity and magnitudes that require units indivisible in quality for measurement. I try to show that this distinction can be best understood as a predecessor to our distinction between ratio scales and absolute scales.

Introduction

Measuring allows us to connect the physical world with numbers – a measure enables us to quantify physical things, processes and states of affairs systematically and in a way that tells us something about the world.[1] From very early on in the history of mankind measurement played an important role in communities – measuring length and surfaces for land-surveying, measuring weight in the context of trade, etc. And it is clear that for purposes of measurement we need different units for different aspects that we measure: if we just look at the Greeks, on whom I will concentrate in the following, we find, for example, *oboloi* for weight, *kotulai* for volume and *daktuloi* (fingers) for the measurement of length.[2] These measurement units are usually arbitrary[3] – using centimetres is no less natural than using inches or fingers or any other measurement unit we please to employ (though some will be more useful than others in certain contexts and some originally derive from human body parts and thus are more readily available).

Furthermore, not only do we distinguish between different measurement units but also between different kinds of scales: we know, for example, that with additive measures, like the measurement of length, 20 cm is twice as long as 10 cm, while with non-additive measures, like with temperatures, 20 degrees Celsius is not twice as hot as 10 degrees Celsius (cf. also below).

While mention of different measurement units can be found in texts going back to the beginning of what has been transmitted to us, an awareness of the differences in scales seems to be a later phenomenon. In Western thought we find the first inkling of it in Aristotle. He is the first thinker in Western tradition providing us with a theory of measurement,[4] and in the course of developing this theory he also touches upon differences in scale. But before we look at this first account of different scales, let us briefly remind ourselves of the role scales play for measurement and the kind of scales we usually employ. This will serve as a useful background for Aristotle's understanding of measurement. I should also say that I am only interested in philosophical accounts of measurement here and have to disregard more technical ones.

Scales in Today's Measurement Literature

The centrality of scales for the understanding of measurement can, for example, be seen in a standard account of the basic tasks of any theory of measurement:

> A conceptual analysis of measurement can properly begin by formulating the two fundamental problems of any measurement procedure. The first problem is that of representation, justifying the assignment of numbers to objects or phenomena [...]

> the second fundamental problem for a theory of measurement: determine the *scale type* of the measurements resulting from the procedure (my italics) (Suppes, 2003).

This account by Patrick Suppes, a central figure in the contemporary philosophical literature on the theory of measurement, makes it clear that determining the scale type we need for our measurement is crucial since it is one of two central problems any measurement theory faces.[5]

Today we mostly use the following kinds of scales:[6]

a) Ordinal scales: with some quantities, all that a scale determines is order. For example, the Beaufort wind scale, which classifies winds, is an ordinal scale – there is no absolute zero, and the score a wind speed possesses on this scale is only meaningful for comparisons. Similarly, Mohs hardness scale gives us an order of the hardness of minerals from 1 to 10 which is determined by the material's ability to resist scratching. While the difference between 10 cm and 9 cm is the same as the difference between 9 cm and 8 cm, namely 1 centimetre, the difference in hardness between a diamond, which has a Mohs hardness of 10, and a sapphire, with a Mohs hardness of 9, is not the same as the difference between a sapphire and a topaz, which has a Mohs hardness of 8; rather, the first difference is in fact more than twice that of the second. So, a difference between one scale point and the next may have different meanings depending on the place where we find the point on the scale. All we can say with the help of such ordinal scales is that one thing is harder, less hard or of equal hardness than another; we can order things according to their hardness, but we cannot meaningfully add or subtract degrees of hardness, nor can we multiply or divide them.[7]

b) Interval scales: these scale types do not possess a true zero; for example, if we measure temperature in Fahrenheit or Celsius, zero degrees Celsius or Fahrenheit does not indicate that there is no temperature (in the way that zero centimetres or inches indicates that there is no length).[8] The zero point is arbitrary and at different temperatures with these two scales (zero indicates the freezing point of water in Celsius, while water freezes at 32 degrees on the Fahrenheit scale). Accordingly, while we can add and subtract temperatures, we cannot multiply or divide them – for example, for both Fahrenheit and Celsius minus 40 degrees indicates the same temperature, but minus 20 degrees Fahrenheit is much colder than minus 20 degrees Celsius – we see that it is not clear what 'half of minus 40 degrees' would amount to.[9]

c) Ratio scales: probably the most well-known scale types are ratio scales, such as length or weight. While it possesses an absolute, i.e. non-arbitrary zero point, the unit can be chosen arbitrarily. The ratio of any two measurements, however, stays the same and is independent of the units I use. For example, the ratio of the length of my desk to its breadth is the same no matter whether I measure it in centimetres or in inches. Thus interval scales allow for adding and subtracting, as well as multiplying and dividing.

d) Absolute scales: finally, with an absolute scale we simply determine the cardinality of a set of things, what we ordinarily call counting.[10] The scale used is 'absolute', because there is no choice of a measurement unit or zero involved. If you want to count the chickens in your backyard then your unit is 'chicken' – you cannot use another, say, somewhat smaller unit (in the way you can use centimetres instead of inches) or else you are counting something different, chicken wings, for example.[11]

Let us now look at Aristotle's account of measurement to see what role differences in scale play with him.

The General Concept of Measure in Aristotle's 'Metaphysics'

Overview of Aristotle's account

In his *Metaphysics*, Aristotle provides the first treatise on measurement we possess in Western thinking.[12] In this treatise we see that for Aristotle a measure is characterised by four basic features:

(1) Measure is that by which the quantity is known – this is its general task.
In order to fulfil it, a measure has to meet the following three requirements:
(2) A measure always has to be homogeneous with what is to be measured;
(3) It is most accurate if nothing can be added or subtracted without it being noticed;
(4) It is simple either in quantity or quality.

We will see that it is feature (4), simplicity either in quantity or quality, which introduces differences in scale. But before we start a discussion of this feature, we should first reconstruct Aristotle's understanding of measurement in this passage more generally. For this reconstruction it will be helpful to have a brief look at what we usually expect a measure to do.[13] This will help us to make explicit some features that Aristotle assumes implicitly and to show how certain features that may sound odd in Aristotle's account are in fact predecessors of features we also assume in contemporary accounts of measurement.

Measurement in general

In order to measure something, we have to decide first which aspect of a thing we want to quantify – for example, whether we want to measure the volume of an object, its temperature or its density. How much of this aspect a thing possesses can then be determined by using a measurement unit that possesses this aspect and by figuring out how often the unit has to be used to measure out the amount in question. In this way measurement units allow us to assign what is to be measured to a certain number. Thus in order to measure something, three things have to be taken into account:

(1) We have to specify the respect in which something is meant to be measured – whether we are going to measure the weight or rather the length of a table. This respect is called the 'dimension' in contemporary measurement literature.[14] Thus by 'dimension' we should not just understand spatial dimensions, but all kinds of respects that we may want to measure.[15] Which respect we examine has to be chosen before we can start measuring – there is no point in bringing my weights for measuring if it then turns out that we are actually going to measure temperatures.

(2) What is to be measured can be quantified by *assigning* it to the number series in a systematic way. The rule of assignment has to guarantee that under the same conditions the same assignments will be made, and under different conditions different assignments are possible.

(3) Finally, we need to agree on *units* to carry out this quantification of a certain dimension. A certain amount of the dimension in question is taken as a unit, for example, a metre or a foot is taken as a unit for length, so that what I want to measure, say the length of my table, can be determined as a multiple of it.

The units used for measurement have to be chosen in accordance with what we want to measure, both have to be of the same dimension. We will see that Aristotle captures this as a 'homogeneity' requirement.

Analysis of Aristotle's account

If we now look at Aristotle, we can see that he is aware of the dimensionality of a measure, and distinguishes it clearly from the units used for measuring, as is obvious from passages like the following:

> [...] the measure of each is a one – in length, in breadth, in depth, in weight, in speed. For 'weight' and 'speed' are common to both contraries; for each of them has two meanings – 'weight' means both that which has any amount of heaviness and that which has an excess of heaviness, and 'speed' both that which has any amount of movement and that which has an excess of movement; for even the slow has a certain speed and the comparatively light a certain weight (1052b25–31).

This passage shows that Aristotle expressly differentiates between the *dimensionality* of certain magnitudes (weight and speed as *dimensions* are also attributed to light and slow things) and the *amount* of these magnitudes which tells us the times a unit is contained in what we want to measure (heavy and speedy is called what has a considerable degree of weight and speed, i.e. what contains the basic unit, for example, 1 kg, multiple times). Assigning what is to be measured to numbers is not a separate step for Aristotle, since for him numbers are the multiple of a basic unit – there is no 'two' as such, but a 'two' that is the multiple *of* the unit 'cup', two cups, etc.[16] Thus numbers are necessarily tied to the dimension of a basic unit.[17]

Let us now look back to the four characteristics of a measure according to Aristotle's account.

(1) We saw that the essential task of measurement is to allow us to know the *quantity* of something: 'For measure is that by which the quantity is known' (1052b20). Of a quantity we always want to know *how much* or *how many* it is – and a measure obviously enables us to answer this question. This is a feature which fits with our contemporary accounts of measurement, even if we did not explicitly introduce it as a separate characteristic in our discussion above. To fulfil this function, a measure needs certain characteristics which are expressed by the following conditions of Aristotle's concept of measurement, what we can call homogeneity, accuracy and indivisibility requirements.

(2) Homogeneity requirement: with Aristotle a measurement unit always has to be homogeneous with the thing measured:

> But the measure is always homogeneous (with what is to be measured), it is of magnitudes a magnitude, and in particular of length a length, of breadth a breadth, of sounds a sound, of weights a weight, of units a unit (1053a24–27).

According to this passage, the dimension has to be the same for the measure and what is to be measured – if we want to measure a length, for example, we need another (smaller) length to measure it, while for the measurement of weight we cannot use a length but rather need another weight. This homogeneity constraint corresponds to the requirement in modern measurement theory that the measurement unit has to be of the same dimension as what is to be measured. However, in Aristotle this homogeneity requirement is implicitly restricted in that the dimension to be measured turns out to be always conceived of as simple, that is, only using a dimension of one kind.[18] By contrast, modern conceptions also allow for complex dimensions. For example, when measuring speed our measure is kilometres/hour or miles/hour, thus combining two different dimensions, time and space.

(3) Accuracy requirement: a measure is most accurate if nothing can be added or taken away without it being noticed:

> Where it seems to be impossible to subtract or add something, there the measure is accurate [...]. For in the case of a furlong or a talent or of anything comparatively large, any addition or subtraction might more easily escape our notice than in the case of something smaller; so that the first thing from which, as far as our perception goes, nothing can be subtracted, all men make the measure, whether of liquids or of solids, whether of weight or of size (1052b35–1053a7, Ross's translation with alterations).

If a unit is of the right size relative to what is to be measured in that nothing can be added or subtracted without it being detected by perception, then that unit is accurate (I call it 'accurate' in accordance with the terminology of the measurement literature, where this means 'being close to the actual value, given the scale'). Aristotle's talk about more or less accuracy of the measure also suggests that to some degree he recognises the problem of error, that is, that there can be variability or uncertainty in measurement. However, the problem of error is dealt with in terms of more and less accuracy, not in probabilistic terms, as we do in modern science, and it is not built into the calculation by ancient mathematicians.

(4) Indivisibility requirement: a measure has to be in some sense indivisible:

> For everywhere they seek the measure to be one and indivisible; and this is what is simple either in quality or quantity (1052b33–35).

In order to understand this passage and what Aristotle means when he talks about indivisibility in quantity and quality we should take into account that a measure involves a quantity *as well as* a quality in some sense, since it is always a quality (what we called 'dimension') which is to be quantified by our measurement procedure. Therefore, it would be strange if Aristotle's 'indivisibility in quality' referred to dimension in general as discussed above. For dimension is involved in every measurement process – it is not as if only some measures would deal with quality in this sense, and others only with quantity.

So what then does he mean by indivisibility in quantity or quality? In order to figure this out we need to take the context of this quotation into account. There we see that indivisibility in quality or quantity is introduced once the question of the appropriate 'one' for measuring different things is discussed. But what does he refer to by the appropriate 'one' for measuring things? He cannot simply mean that we use different units to measure different dimensions, since all the different dimensions he mentions as being measured – length, weight, speed, syllables, intervals, etc. – he sums up as needing one of two different kinds of ones, either a one that is indivisible in quantity or one that is indivisible in quality. Rather, what Aristotle seems to indicate with this division is a further specification of the kinds of magnitude measured according to two different kinds of scales we need: some magnitudes need units simple in quality as a basis – he also calls them 'indivisible in *eidos*' (1087b34–1088a3) or 'indivisible for knowledge' (1052a32–33). Other magnitudes need units that are quantitatively simple, which Aristotle explains as indivisible with respect to perception (1088a2–3). In both cases the measurement units have to be treated as indivisible because they are serving as the basis for our measurement procedure in such a way that what is to be measured can be expressed as the multiple of this basis.

While Aristotle does not spell out this difference any further, he gives a couple of examples for each of them. So let us look at some of these. We will start with indivisibility in quantity or for perception. As an example Aristotle uses the foot:

> The one [the foot] must be placed among things which are undivided with respect to perception, as has been said already – for every continuum is equally divisible (1053a23–24).

Of course, a foot is always further divisible in principle, since it is a continuum. But when we want to use it as a unit to measure out something else, like the length of my room, we treat it as being indivisible in order to have a unit of which we can have a multiple. The foot is our 'indivisible' one with the help of which we quantify the length of my room – it allows us to determine how many times the foot fits into the length.[19] These units seem to be called 'quantitatively indivisible' because in order to serve as a basis for measuring, these units have to be treated as indivisible in their quantity; the foot is seen as indivisible in its extension. And it is indivisible for perception, since for our perception the foot is given as a whole in nature – originally our own foot – and hence as something we perceive as one thing. It is something that cannot be further divided in so far as it is a given whole. We use such units that are indivisible with respect to perception in order to quantify continua like length.

Measurement units that are indivisible in quality, Aristotle seems to illustrate, among other things, with the example of a human being, a letter in speech (φωνη), a syllable in rhythm and a semitone/quartertone (δίεσις) in music.[20] In how far are these units indivisible in quality? Aristotle's basic idea seems to be that if we divide such units further, we are not simply deriving something of the same kind (only a smaller quantity of it), but rather we are actually getting something that possesses a different quality: if we attempt to divide a letter like 'ε', epsilon, we will not get any properly articulate sound any longer and thus we are leaving in some sense the realm of speech. To prevent leaving our conceptual basis, we have to take the letter as an indivisible unit. Similarly, if we take the semitone in the diatonic scale as our basic unit,[21] we can of course divide the string on a monochord further, for example, between what we would call E and F, but this will not get us a tone that belongs to our musical scale any longer. Rather, we will interpret such a tone as a badly played E or F.[22] Attempting to divide such a unit indivisible in quality would lead to something that is no longer a part of the respective field (of our musical scale or of speech). Accordingly, these units are indivisible in *eidos* or to knowledge, because if one tries to divide such a unit further, it will not fit its definition any longer. Units that are indivisible in quality or *eidos* or knowledge are conceptually indivisible. By contrast, units indivisible in quantity could in principle be divided and still be used as a unit for measuring the same magnitude; for example, in principle we could use a half foot as our basic unit to measure the length of our table.

Prima facie the distinction between indivisibility in quantity and indivisibility in quality may remind us of the modern distinction between intensive and extensive magnitudes, that is, the distinction between additive and non-additive magnitudes. However, Aristotle's position does not square with this central modern distinction. For both kinds of magnitudes, intensive and extensive ones, are actually part of what is measured with units indivisible in quantity, both are continua of sorts. Rather, the important difference between the two magnitudes pointed out by Aristotle is that with magnitudes measured by units indivisible in quantity or to perception we are quantifying something continuous, while with magnitudes measured by units that are qualitatively, i.e. conceptually indivisible, we are quantifying discrete magnitudes.

In modern measurement theory we do not talk about scales using units quantitatively and qualitatively indivisible but rather about ratio and absolute scales. For the difference between these two scales seems to be what Aristotle is capturing with indivisibility in quantity and quality: ratio scales, where the unit but not zero can be chosen arbitrarily, seem to be what Aristotle refers to with units indivisible in quantity: different units can be chosen (for Aristotle these are more or less accurate, a foot provides more accurate results than a *stadion*)[23] and the examples of magnitudes he understands to be measured by such units – length, weight, etc. – show that zero cannot be arbitrary in these cases. By contrast, absolute scales, where neither an arbitrary choice of a unit nor of zero is available, seem to correspond to Aristotle's units indivisible in quality, with which he thinks we quantify the number of members a collection of discrete things possesses.[24] Some modern measurement theories connect what Aristotle calls 'indivisible in quality' with counting, rather than with measuring. And indeed also Aristotle does not always view it as part of the field of measurable quantities; he sometimes understands measuring in a strict sense as quantifying a continuous magnitude in contrast to counting.[25] Quite often, however, we find a wider notion of measurement in Aristotle that comprises what we would call measuring and counting.[26] But whether or not we include units indivisible in quality among a wider notion of measurement or not, this distinction clearly shows that Aristotle for the first time tried to give a systematic account of measurement which recognises that different magnitudes have to be quantified with different kinds of scales.[27]

Notes

[1] I am restricting myself to measures within the context of science and natural philosophy, and leave out questions of normative and aesthetic measures here.

[2] Cf. Richardson (2004). The units varied, however, according to different city-states and times.

[3] I am leaving out so-called natural units that are only defined in terms of physical constants, like the Planck unit.

[4] For a detailed discussion of his theory of measurement see my (2017) paper, with which this paper overlaps in some parts.

[5] By scales Suppes understands 'a class of measurement procedures having the same transformation properties'.

[6] Cf. also Suppes (2003). I leave out nominal scales here, which basically function like labels; nor will I deal with the distinction between fundamental and derived scales of measurement. The scale types are given in order of strength – extra requirements are added from the first kind of scale to the second, etc.

[7] Ordinal scales do not possess a relative degree of difference, in contrast to interval scales. While interval scales allow for subtraction and addition, ratio scales also allow for multiplication and division.

[8] The Kelvin temperature scale, however, has a true zero.

[9] Why a lack of absolute zero leads to a lack of constant ratios may become plausible if we imagine using a ruler for measuring length where the beginning, our zero, has broken off, and we have to start our measuring process at, say, 5 cm. Then we can certainly add more centimetres, but when we have measured something that reaches the mark of 15 cm on this ruler, it will not be half of something that reaches 30 cm on this ruler.

[10] Suppes characterises it as follows: 'The number of members of a given collection of objects is determined uniquely'.

[11] Treating counting as a measuring procedure is supported by the fact that we talk about two groups being equal in number just as we talk about them being equal in other qualities; we can compare two groups simply with respect to the numbers of their elements. Nevertheless, some scholars do not want to subsume counting under measuring (so, for example, Berka (1983, p. 109), who objects to understanding counting as a form of measurement, since with counting we 'abstract from the qualitative specifications of the elements counted'). But since we will see that Aristotle does include counting at least in his wider notion of measurement, for our purposes absolute scales should be understood as one possible type of measurement scales.

[12] Book Iota, chapter 1, especially 1052b16–1053b8. We also find some discussion in *Metaphysics* book Δ, chapter 6 and book Δ, chapter 1. There are some ideas concerning measurement in earlier thinkers, for example, in Anaximander, Heraclitus, Diogenes of Apollonia, and the Pythagoreans, but they do not provide a full account of what measurement means. And while we find substantial discussions of measurement in Plato's *Philebus* and the *Laws*, it is there discussed mainly as a metaphysical and ethical notion, and not as what we can see as

a forerunner to contemporary measurement theory. In the *Timaeus* Plato uses the notion of a measure within the context of astronomy (cf. Sattler, forthcoming) but without analysing this notion any further. And Protagoras's claim that man is the measure of all things – perhaps the most famous slogan on measure from ancient times – seems to have been an epistemological claim, not connected to any theory of measurement.

[13] The background to this section is Krantz et al. (2006) and Ellis (1968).

[14] In fact, the English word 'dimension' derives from Latin 'dimetiri', which means 'to measure out', see the OED entry on 'dimension'.

[15] Cf. also Ellis (1968, p. 139) who points out that we speak of 'the dimension of length, mass, time interval and so forth'.

[16] This fits with the principle of homogeneity prevalent in the mathematics of Aristotle's time. But it is not to be found with Plato and the early Academy against whom Aristotle argues in *Metaphysics* M and N. It is part of Aristotle's attempt to ensure that objects of mathematics do not exist separately from physical particulars. For him, also the mathematicians work with numbers of something, only this time it is not cups but indivisible units, a two of *monas*.

[17] By contrast, contemporary measurement theory works with a dimensionless number series, whatever our metaphysics of numbers may be.

[18] For detailed evidence for this claim and a discussion of the problems this restriction faces cf. Sattler (2017).

[19] We may wonder what to do with a room that is 20.5 feet across, if we follow Aristotle. In fact, fractions of a unit are a problem not only for Aristotle but for Greek mathematics more generally. The way to deal with this problem was usually to find an adequate subunit as the new unit, for example the unit 'finger' in our case.

[20] See 1052b33–1053a24 and 1087b34–88a11. It is semitones or quartertones depending on which musical scale is used.

[21] The example of the *diesis* is complicated by at least three factors: (a) the *diesis* could either refer to empirical harmonics or to mathematical ratio theory; (b) ancient musical theory recognises different harmonies with different *dieses* (see Barker, 1989, pp. 215–6); I have chosen one of them here, the diatonic one, to make the point clear; and (c) musical intervals are not additive measures, since they are conceived within a system of intervals.

[22] In ancient musical theory an octave consists of two tetrachords (in a diatonic scale these are divided into two tones and a *diesis*) and a tone in between the two tetrachords. A *diesis* is a little bit less than a half tone in our modern diatonic scale (and a tone minus this *diesis* could also be called a *diesis*, but would be slightly more than a half tone – this seems to be the reason why Aristotle refers to two half tones in 1053a14–18). A *diesis* is the smallest division in the scale; it measures the octave and can as such not be divided. Mathematically we can, of course, divide the half tone further, but then we do not have a unit for our octave of sounds any longer; rather we move from measuring the octave musically to measuring mathematical intervals.

[23] While Aristotle also refers to two different half tones in 1053a14–18, this variety in units does not mean that also with indivisibility in quality units can be arbitrarily chosen; rather this particular case is due to peculiarities in Greek musical theory, cf. above.

[24] We may think that temperature and hardness units should also fall under what is indivisible in quantity, since they are continua of sorts. However, they do not seem to fit Aristotle's idea of being indivisible for perception: the temperature of water boiling may seem indivisible for our perception, but it does not give us a unit that we can then use to measure out the whole temperature range (a diamond may seem to play a similar role on the hardness scale, as the hardest thing we have come across, but again it cannot be used to measure out the whole range).

[25] See, for example, *Metaphysics* Δ 13, 1020a8–11.

[26] For example, when he calls measuring what we would call counting of horses in 1088a8–11.

[27] I want to thank my colleague Kevin Sharp for helpful comments on the paper.

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No.	Author	Title	Series
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Insights

Insights is edited by Nicholas Saul, IAS Director and Professor of German Literature and Intellectual History.

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