Chapter 8
Seriation: Graves in the Münsingen-Rain burial site

Abstract
Main topics. The burial site of Münsingen-Rain is situated on a ridge and contains a large number of graves, many of which contain artefacts. The graves have been dated by their distance from the village by Hodson. Is it also possible to statistically validate this dating from the artefacts in the graves? **Data.** An occurrence table of graves by artefacts consisting of ones (artefact present in the grave) and zeroes (artefact absent from the grave). **Research questions.** Is it possible to validate the archeological chronology of the graves by applying statistical procedures on the table of occurrences? **Statistical techniques.** Correspondence analysis, validation results.

Keywords Celtic graves · Artefact fashion · Münsingen-Rain cemetery · Switzerland · La Tène · Seriation · Correspondence analysis

8.1 Background

One of the core questions with archeological excavations is the age of the objects or artefacts found in graves.[1] Not much can be done to understand the material without knowing its age. At present, chemical analysis is a main contributor to establish the age of uncontaminated material, in particular radiocarbon C14 dating for organic materials and thermoluminescence for pottery. However, there are other ways to

[1] Valuable comments on an earlier draft were made by Prof. Ruud Halbertsma, Curator Greece and Rome, National Museum of Antiquities, Leiden, The Netherlands.

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establish age, especially in those cases when carbon dating is not feasible; and it is always valuable to validate outcomes of one method via another method. For instance, extensive efforts were carried out to validate dating by tree rings via calibrations with radiocarbon dating; Clark (1974).

In this chapter I will approach the chronology problem statistically, and compare the ordering of the graves with dating based on archeological arguments, in particular the positions on a ridge emanation from the village Münsingen-Rain.

The key technique used in archaeological data analysis is *seriation*, also called *artefact sequencing*. There are several definitions of seriation, but here I will refer only to Liiv's: '*Seriation* is an exploratory data analysis technique to reorder objects into a sequence along a one-dimensional continuum so that it best reveals regularity and patterning among the whole series'. (Liiv, 2010, p. 71). Note that Liiv sees seriation as useful in a wider context than only ordering in time. In a brief online introduction to seriation, Hirst (2017) makes the interesting observation that 'Seriation is thought to be the first application of statistics in archaeology'.

Today seriation is no longer the mainstay of the dating efforts of archeologists, partly because it can only be used for *relative* rather than *absolute* dating. As will be explained below, seriation based on artefacts also rests on the assumption of *fashion*, probably first envisaged by the Egyptologist Sir William Flinders-Petrie (1899), cited in Kendall (1971) .

In 1968 a cooperation among mathematicians, statisticians, and archaeologists led to a dedicated joint conference on *Mathematics in the Archaeological and Historical Sciences*. According to Liiv (2010, p. 77), the Proceedings, edited by Hodson, Kendall, and Tăutu, (1971) to date serve as one of the most comprehensive collections on research done on archaeological seriation.

There are many other applications of statistics to archeological problems, such as finding out whether archeological objects found in a burial site are randomly distributed over the entire burial site or whether they are concentrated in specific sections. When settlements are built on top of another, *stratification* is an obvious way to obtain a relative dating of settlements. This is, for instance, the case with the city of Troy, located at Hisarlik in Anatolia, Turkey, and made famous to this day by Homer. Using stratification might seem the ideal method for dating in the field, but in a level burial site that has been in use for many centuries, this is not really an option. Statistical techniques such as spatial analysis can assist in the dating, as was, for instance, demonstrated by Graham (1980, 1981) for the Iron Age Hallstatt burial site in Austria. An overview of the state of affairs in the 1970s can be found in the proceedings by Hodson et al. (1971) mentioned earlier; a more recent overview was published by Liiv (2010).

8.2 Research questions: A time line for graves

> The Late Iron Age burial site of Münsingen-Rain is situated in the Aare valley between Bern and Thun [i.e., was roughly used between 450 BCE and 100 BCE; some 50 years before Caesar invaded Gallia] .

> [...]Due to the size of the burial site, the well-documented excavation and the abundance of grave goods, Münsingen is an indispensable reference for chronological aspects of the Late Iron Age. (Moghaddam, Müller, Hafner, & Lösch, 2016, p. 149)

The burial site is located in the north-south direction along terraced land running out from the village Münsingen. It was excavated around 1906 and was first published about by Wiedmer-Stern (1908) (see Figure 8.1).

The dating and sequencing of the graves is obviously of prime importance so that the archaeological finds can be understood in the temporal and local context, but also in the link to other Celtic burial sites in Europe. The major work on archaeological seriation of the graves at this site was carried out by Hodson (1968). It was Kendall (1970, 1971) who started and for a large part developed the statistical approach to seriation for the site, using Hodson's tables indicating which artefacts had been found in which graves.

8.3 Data: Grave contents

The data for this example consist of an *incidence matrix* of 59 graves (rows) and 70 artefacts (columns) recovered from the graves. The entries in the matrix indicate whether an object was present (= 1) or not (= blank), hence the name 'incidence matrix'. An alternative would have been an *abundance matrix*, in which the entries indicate how many of a particular kind of artefact were present in a grave.

In the left-hand panel of Figure 8.2 there is no particular order either for rows or for columns. It was created by Kendall (1971) from Hodson's original incidence table . A statistically reordered table is shown at the right.

Fig. 8.1 A Sunday excursion to the excavations at Münsingen-Rain (July 1906) Excursion led by Jakob Wiedmer-Stern (far left). Source: Archives of the Bernisches Historisches Museum, Bern, Switzerland; reproduced with permission of the Museum.

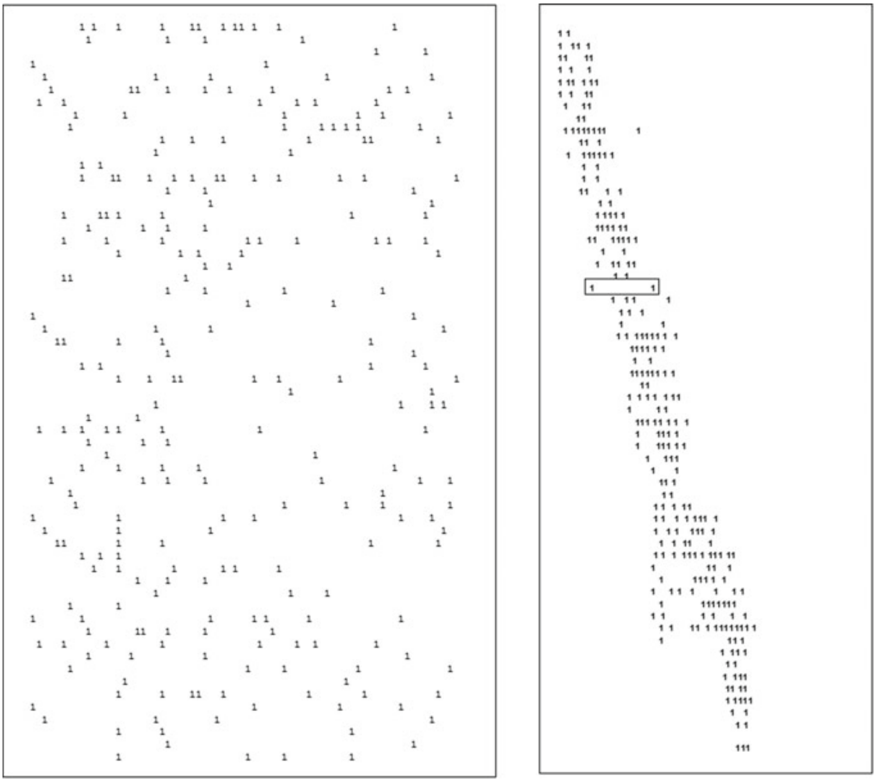

Fig. 8.2 Münsingen-Rain data: 59 graves (rows) and 70 artefacts (columns). ∗Left-hand panel: Unordered incidence matrix. 1=artefact is present; blank = artefact is absent ∗Right-hand panel: Statistically reordered incidence matrix ∗The box in the right-hand panel indicates Hodson's Grave 48.

8.4 Analysis methods

Various techniques have been applied to create ordered incidence matrices, see Liiv (2010). For a successful seriation of the incidence table it is important that there is an underlying order for both the row variable (here graves) and the column variable (here artefacts); we just do not know beforehand what these orders are.

The graves and artefacts do not have a specific dependence structure, i.e. it is not a question of which one of the variables predicts the other. In contrast, we have an internal structure design in which the relationship between rows and columns is to be examined (see Section 3.10, p. 84 for an explanation of these designs). The time order of the variables leads to similarities between graves and between artefacts, because graves of the same age are expected to contain approximately the same types of objects.

To recover these orders correspondence analysis (see Section 3.10.1, p. 84) is an appropriate technique. A good introduction to correspondence analysis for archaeologists can be found in Chapters 5 and 6 of Baxter (1994) and in De Leeuw (2013)[2]; a good practical general introductory book is Greenacre (2017).

8.5 Münsingen-Rain graves: Statistical analysis

For a successful seriation there has to be a natural order underlying both graves and artefacts. That there is a natural order for the graves is not in question; in fact it is the recovery of this order that is the purpose of the exercise. For the artefacts the situation is different; we need a conjecture as to why they may be ordered.

8.5.1 Fashion as an ordering principle

That there is an ordering underlying the artefacts rests on the assumption that artefacts are subject to fashion. This hypothesis was probably first posited by Sir William Flinders-Petrie (1899), as mentioned in Kendall (1971). The rationale behind this is that initially a particular form, style or decoration of an artefact (ring, fibula, necklace, sword) does not exist; then it is created, becomes popular, and gradually drops out of favour again. This idea was reiterated by Müller et al. (2008) 'This led [...] to the recognition that some types of ornament (for example, torcs, anklets or bracelets,[..]) were replaced sequentially over time; similarly, certain combinations of objects of personal adornment proved to be chronologically sensitive'. (p. 463).

This process is illustrated in Figure 8.3. The fashion effect is that at one time certain objects in a specific form are not present in the graves, later graves do have the objects with this form, and still later graves will no longer have this form. but its successors in style instead. Given a long enough time span, graves at the beginning and end of the time line will not have any forms of artefacts in common. Naturally this is an idealised sketch of the situation, as some graves will contain precious objects from the past and thus introduce uncertainties in the time line of the graves. However, a sturdy analysis technique such as correspondence analysis should be able to deal with this, and even signal anomalies.

[2] There are at least three almost identical papers under the same name. The 2013 is the latest one. https://escholarship.org/uc/item/3m18x7qp; accessed: 15 June 2020.

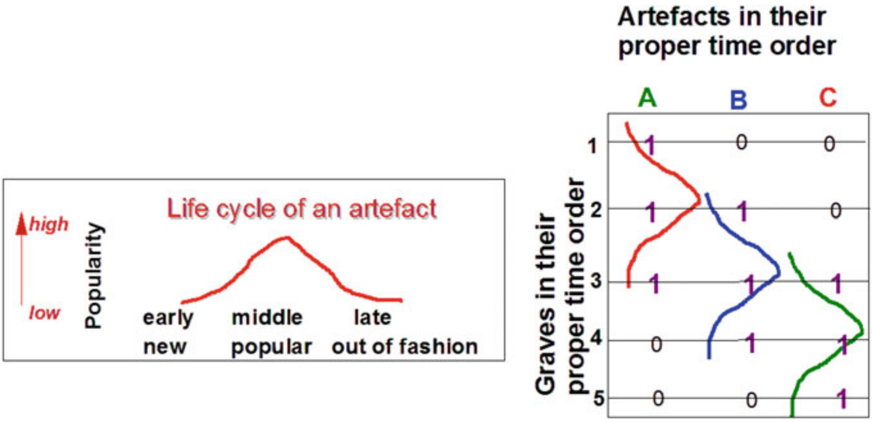

Fig. 8.3 Münsingen-Rain chronology How fashion and time create an ordered incidence matrix.

8.5.2 Seriation

How effective correspondence analysis is in the seriation of the Münsingen-Rain data is apparent from the right-hand panel of Figure 8.2. The graves and artefacts are now ordered in such a way that there is a steady diagonal from one corner to another. As remarked earlier, this type of seriation only provides a relative dating, not an absolute one, because we do not know whether the time line starts at the bottom or at the top. Also the time intervals between sequential graves are not known. To settle this issue archaeological information is indispensable. In addition, the right-hand panel also shows that at some places the ordering seems arbitrary, and that there are artefacts in graves where one would not expect them given the recovered ordering. Incidentally, it should be remarked that correspondence analysis does not necessarily provide a unique solution for seriation itself, so that in general we will have to validate the results by other means, statistical and/or archaeological, for instance, by looking for parallels from dated fields elsewhere.

One further caveat needs to be made. It is common to evaluate the quality of the results from a correspondence analysis on the basis of the proportional amount of fitted variability, referred to as *inertia*. More details about inertia are presented in the correspondence-analysis section of Section 3.10.1 (p. 84). Each of the coordinate axes of the analysis contributes to this inertia. In most applications the proportion of explained inertia of the first two coordinate axes is substantial, but in a large (59×70) and sparse table (6.6% nonzero cells) as we have here this is typically not the case. In this study the proportion of explained inertia of the first two axes is only 14%. Such values seem to be characteristic of sparse tables and do not necessarily reflect the quality of the representation of the patterns in data such as those used here. 'These percentages do not have the same significance when we are dealing with a contingency table because the binary coding introduces noise that reduces the

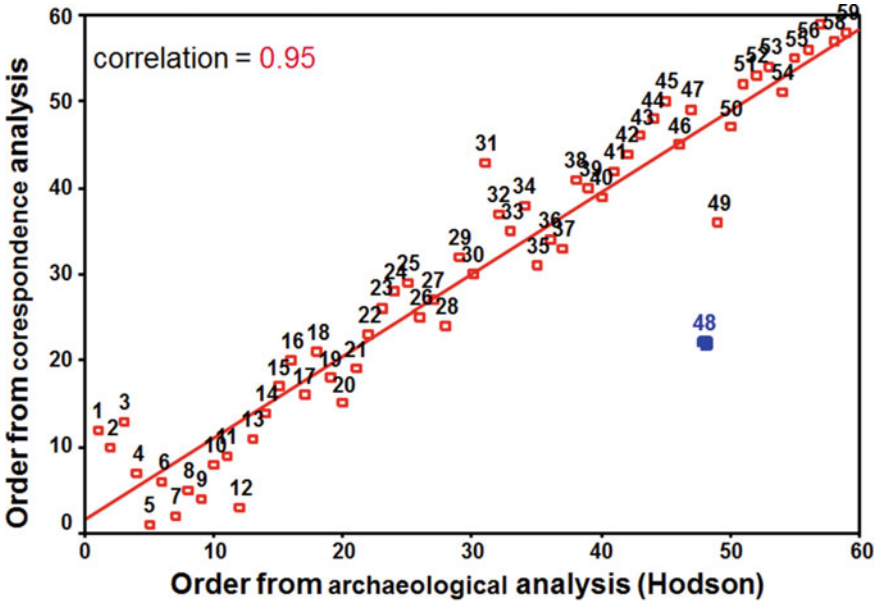

Fig. 8.4 Münsingen-Rain: Comparison between Hodson's archaeological order and the statistical order from correspondence analysis. The numbering of the graves is Hodson's. If the orders were identical, all graves would lie on the straight line. Grave Hodson no. 48 was ordered as no. 22 by the correspondence analysis.

proportion of variance explained associated with each eigenvalue' [an *eigenvalue* represents inertia explained by each coordinate axis] (Lebart et al., 1998, p. 77).

8.5.3 Validation of seriation

The most obvious validation of the statistical results from the correspondence-analysis seriation is to compare them with the archaeological information. As mentioned above, the Münsingen-Rain burial site is located on a ridge starting from Münsingen; it is reasonable to suppose (and validated as well) that the oldest graves are closest to the original La Tène settlement near Münsingen, and that the graves become younger further down the spur. On the basis of this and additional evidence, Hodson established a time line for the graves and numbered them according to their presumed age. The details can be found in Hodson (1968, plate 123) and Kendall (1971).

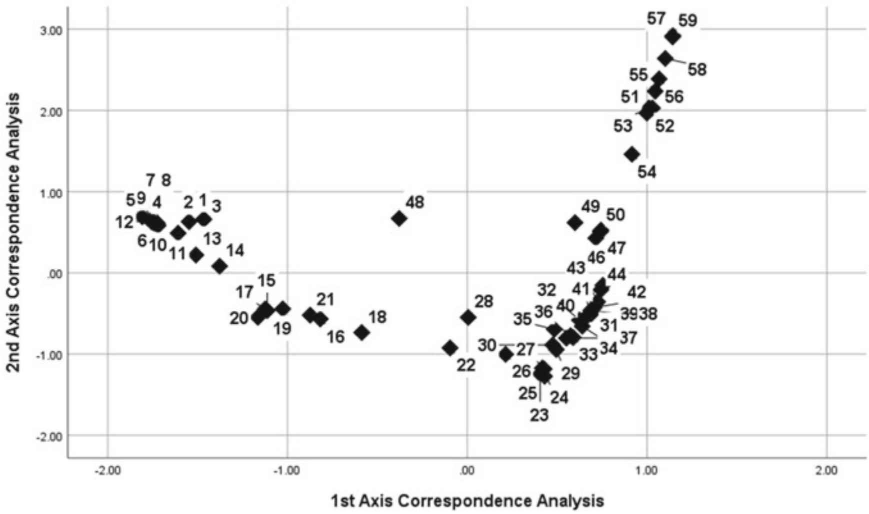

Fig. 8.5 Ordering Münsingen-Rain graves Graves arranged according to their coordinates on the two correspondence-analysis axes.

Figure 8.4 shows the extremely high correlation (0.95) between Hodson's ordering and the statistical seriation from a correspondence analysis. The numbering of the graves is Hodson's and shows the time line of his order. This points to valid results from both Hodson's archeological order and the correspondence analysis. About the same order was also found by Wiedmer-Stern (1908); see Meulman (1982, p. 157) .

This figure also shows Grave 48 as a curious outlier. In the correspondence-analysis seriation this Grave was number 22. Obviously, its content must have been rather ambiguous, as the two positions in the ordering do not agree at all. Inspecting the box in Figure 8.2 we see that Grave 48 contains only two artefacts which are relatively far apart. Further details about the artefacts can be found in Hodson et al. (1971, pp. 15, 16, 47). The 'suspect' Grave 48 has been the subject of a discussion between Hodson and Kendall, in which it became crystal clear that statistics alone was not enough, but solid archaeological input was necessary to resolve the anomaly. Hodson also raises the point of heirlooms being present in younger graves.

Especially in the early periods of statistical seriation, one of the ways to demonstrate the outcomes was by means of plotting the first two coordinate axes of a correspondence analysis against each other. Kendall (1971, p. 228) made a similar plot based on his multidimensional scaling analysis. As can be seen in the figure in Kendall's paper and our Figure 8.5, both plots have a *horseshoe* shape. Technical arguments indicate that horseshoes occur when the objects (graves) have a strong ordering. This strong order can also be seen in Figure 8.2. Diaconis et al. (2008, p. 777) show that,'in general, a latent ordering of the data gives rise to these patterns [i.e. horseshoes] when one only has local information. That is, when only the interpoint distances for nearby points are known accurately'. In the seriation this is clearly the case, as overlapping fashions in artefacts are phenomena found in graves at adjacent time points.

What is obviously lacking from the treatment presented here is a proper attention to the artefacts themselves—so far they have only been a vehicle for seriation. Hodson (1970) and Hodson et al. (1971) contain both archaeological and statistical discussions on grouping or clustering the artefacts; see also Wilcock (1995).

8.5.4 Other techniques

Our analysis is in a sense a fairly conventional one for this type of seriation data. Many other clustering techniques, often in conjunction with multidimensional scaling or correspondence analysis, have already been applied to the artefact data.

These data were also used to evaluate new numeric techniques. For instance, Meulman (1982, p. 66, 156–162) carried out extensive studies with the Münsingen-Rain data within the context of variants of correspondence analysis, and used these data to evaluate various strategies for handling missing data, referring to both the dimensional representation and the pattern in the rearranged data matrix.

At present, in the four years preceding the writing of this chapter, Hodson (1968) was cited 20 times, 8 of which were in purely mathematical treatises using the data as an example. Wilcock (1999) provides a more general overview of statistical techniques in archaeology for the preceding 25 years, including references to the Münsingen-Rain data. Finally, Baxter (1994) produced a general and practical textbook on multivariate statistics for archeologists.

Even though this chapter is about seriation, the data from the Münsingen-Rain burial site also raise archeological questions; see Hodson (1968), Harding (2007) on Celtic art, and Müller et al. (2008) on social rankings of families.

8.6 Other approaches to seriation

The proceedings of the Anglo-Romanian conference on *Mathematics in the archaeological and historical sciences* (Hodson et al., 1971, pp. 173–287) contain several examples of seriation, dealing with such diverse topics as the works of Plato, anthropomorphic statuary, epigraphy, and the travelling salesman problem. On p. 263 Hole and Shaw (1967) are cited as having given an extensive account of sequencing methods. A more recent version of the history of seriation was provided by Liiv (2010). She mentions seriation work in several disciplines and lists applications in archaeology, anthropology, cartography, graphics, sociology, sociometry, psychology, psychometrics, ecology, biology, bioinformatics, group technology, cellular manufacturing, and operation research.

8.7 Content summary

The aim of this case study was to put Celtic graves from the La Téne period in a proper time order (seriation) by a statistical procedure. It turned out that the results from statistical seriation procedures could indeed be validated with the archeological information about the layout of the burial site, and vice versa.

The basis for the statistical seriation was the assumption that people's attraction to specific objects (for instance, *fibulae*, brooches) was determined by fashion: at first the objects did not exist, then they became available, later even popular, and finally the objects disappeared again. Artefacts are thus a popularity indicator for the time that the owners were buried. Of course, regularly heirlooms from older fashions were buried as well, thus creating uncertainty about the dating of the graves, as exemplified here in Grave 48: the two artefacts it contained made it difficult to place it unequivocally on the time line of the graves.