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Reinventing the wheel? Modelling temporal uncertainty with applications to brooch distributions in Roman Britain

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ABSTRACT

A simple, simulation-based model of temporal uncertainty is presented that embraces other approaches recently proposed in the literature, including those more usually involving mathematical calculation rather than simulation. More specifically, it is shown how the random generation of dates for events, conditioned by uncertain temporal knowledge of the true date, can be adapted to what has been called the chronological apportioning of artefact assemblages and aoristic analysis (as a temporal rather than spatio-temporal method). The methodology is in the same spirit – though there are differences – as that underpinning the use of summed radiocarbon dates. A possibly novel approach to representing temporal change is suggested. Ideas are illustrated using data extracted from a large corpus of late Iron Age and Roman brooches, where the focus of interest was on their temporal distribution over a period of about 450 years.

1. Introduction

In a review paper, *Modelling Temporal Uncertainty in Archaeological Analysis*, Crema (2012: 441) 'tackles the thorny but *surprisingly neglected* problem of both the quantification of temporal uncertainties and their integration into archaeological analysis' (our emphasis). The present paper examines ways in which this problem might be addressed. It is shown that several recent proposals for modelling temporal uncertainty can be understood within the framework of a simple model of temporal variation. Some detailed illustrative examples are provided, primarily for a corpus of 10,921 brooches from late Iron Age and Roman Britain.

Temporal variation is probabilistically modelled when radiocarbon dates are re-expressed in terms of a probability distribution over a range of calendar dates. Applications are widespread; Crema (2012: 141) largely excludes applications of this kind, where secure absolute dating evidence is available, from his review, and we follow suit. Crema does not intend to imply that archaeologists neglect time; rather that 'we have often neglected the role of time in our quantitative methods, failing to integrate *formally* the temporal dimension as part of other analyses' (our emphasis), and that 'our assessment of time is often restricted to introductory and concluding narratives'.

Our interest in this problem stems from an investigation of regional differences in brooch use patterns in late Iron Age and Roman Britain (Cool and Baxter, 2016). Our realisation that the modelling approach developed there could be used to reinterpret other recently proposed methods prompted the present paper. The background to that study is presented in Section 2. Section 3 expands on the methodology, forming the basis for the illustrative applications of Section 4. Other methodologies that have been proposed recently are explicitly related to our approach in Section 5. Section 6 concludes the paper.

The supplementary material provides additional mathematical and computational background. Version 3.1.2 of R (R Core Team, 2015) was used for all analyses.

2. Archaeological background and data

Table 1, taken from Cool and Baxter (2016), is based on information extracted from Mackreth's (2011) corpus *Brooches in Late Iron Age and Roman Britain*.

A brooch can be assigned to a type and the region in which it

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Table 1
Regional counts of late Iron Age and Roman brooches by TPQ and period. The regions are EA = East Anglia, N = North, S = South, EM = East Midlands, WM = West Midlands, SW = South–West. The periods are IA = Iron Age, AT = Augusto-Tiberian, CN = Claudio-Neronian, FL = Flavian, TH = Trajanic-Hadrianic, AS = Antonine-Severan, L = Late.

TPQ	EA	N	S	EM	WM	SW	Period
−70	25	0	88	20	3	24	IA
−50	25	1	107	29	3	26	IA
−30	13	2	49	11	1	25	IA
−20	0	1	7	1	0	20	IA
−5	6	0	24	3	0	1	IA
1	62	11	141	64	30	95	AT
5	2	0	19	5	0	82	AT
10	173	14	532	157	37	119	AT
15	9	0	26	7	3	3	AT
20	38	4	277	51	15	81	AT
25	3	0	13	0	0	1	AT
30	32	0	56	20	1	14	AT
35	247	26	561	176	50	319	AT
40	31	2	72	41	5	8	CN
45	82	8	203	54	20	339	CN
50	190	8	106	77	28	142	CN
55	297	24	182	119	34	98	CN
60	68	4	68	22	19	48	CN
65	55	10	74	45	64	146	CN
70	29	11	27	22	10	17	FL
75	89	58	106	90	53	140	FL
80	130	70	57	79	35	94	FL
85	161	89	73	142	63	145	FL
95	70	73	26	18	10	22	FL
100	4	5	5	5	13	4	TH
105	10	1	12	2	1	14	TH
110	52	37	58	37	40	49	TH
115	12	25	18	11	13	32	TH
120	10	6	7	17	9	17	TH
125	36	10	38	15	11	53	TH
135	8	7	6	2	3	6	TH
140	21	17	19	7	7	5	TH
145	23	15	11	4	0	15	AS
150	34	50	37	18	11	39	AS
155	10	2	8	7	1	6	AS
160	29	21	15	10	6	14	AS
170	13	18	31	5	2	14	AS
175	22	3	12	10	0	13	AS
180	7	7	15	6	4	6	AS
185	16	3	12	0	0	6	AS
190	68	16	40	16	11	18	AS
200	44	25	28	14	3	16	AS
210	15	19	9	3	0	5	AS
215	19	33	33	8	1	11	AS
275	23	2	3	2	2	11	L
290	3	7	7	2	1	0	L
310	5	3	6	1	1	2	L
340	3	3	3	1	3	1	L
350	8	5	12	2	5	6	L
370	5	0	3	0	2	5	L
400	4	0	7	2	2	2	L

was found. Many of the brooches were not recovered from dated contexts, but the *type* to which they belong can be assigned a *terminus post quem* (TPQ) based on the earliest date for brooches of the type found from dated contexts. Several types may be associated with the same TPQ and have been grouped together in Table 1. That is, the entries refer to counts of brooches from a region whose type has a particular TPQ with type differences for that TPQ being ignored. The period labels are conventional, named, for the most part, after the more memorable emperors or their families who dominated the period.

Cool and Baxter (2016) aimed to compare the regional and temporal distributions of brooch use/loss – as evidenced by the archaeological record. Several problems were immediately encountered because of temporal uncertainty associated with the date of brooch loss, the pattern of brooch loss, and what will be called the *life-span* of a type.

The life-span is determined by the *terminus ante quem* (TAQ), often not known with any precision. Some types were probably short-lived (10–15 years); for other types a life-span of over 100 years is feasible. Some archaeologists (of whom Mackreth (2011) was one) work with what might be called a prior belief that brooch type life-spans are short, so that any late occurrence of a type is treated as *de facto* evidence of residuality. This means that competing archaeological interpretations of the ‘objective’ archaeological record contribute an extra layer of temporal uncertainty to any analysis.

The pattern of loss is impossible to quantify with certainty. In cognate applications (Section 5), the assumption of a uniform distribution is common. This can be a reasonable assumption – essentially acknowledging total ignorance of the pattern (Crema, 2012). For artefact loss it seems qualitatively inappropriate; for example, the ‘popularity’ of a brooch type is more likely to rise to a peak and then decline. How this qualitative idea can be modelled is discussed below.

3. Methods – modelling temporal uncertainty

3.1. Sampling models

Define an *event* of interest, e_i – brooch loss in the previous section. There are n events; e_i occurs between a TPQ, τ_{1i}, and TAQ, τ_{2i}; call the difference between them the *life-span* of the event, L_i. The date of occurrence of e_i is unknown.

Events can be characterised by a set of attributes, for example (Type, TPQ, TAQ, Region) for the brooch data. It is convenient to introduce the concept of *event size*. If a set of events is identical in all respects relevant to an analysis they can be grouped together and ‘Size’ may be treated as an event attribute. In Table 1 TPQ is a surrogate for type (ignoring any type differences where they have the same TPQ) so type becomes a redundant attribute. The entries in Table 1 are the sizes of events from the same region having the same TPQ. This is not restrictive since the date of loss of a brooch can be treated as a unique event with a size of 1 if appropriate.

An assumption in what follows is that events are independent; this would be violated if, for example and in the context of the brooch data, a subset of brooches that constituted an event came from the same site and had a known stratigraphic relationship. Very few of the brooches in the sample belong to such subsets so the development below assumes independence. More generally, a reviewer has suggested that where this is an issue knowledge of stratigraphic information can be integrated into the simulation methodology used.

With this in place the idea is to simulate a set of n random dates, d_i, using the model

$$d_i = \tau_{1i} + L_i \times p_i \qquad (1)$$

where p_i is sampled from a probability distribution, $\Phi_i(x)$, lying between 0 and 1.

Assuming, temporarily, that τ_{2i} and hence L_i are known; practical implementation devolves to choosing $\Phi_i(x)$ to generate dates. A flexible model is the Beta distribution (see the Supplementary Material). For immediate purposes it is sufficient to know that it is defined over the range [0, 1] and depends on two shape parameters, α and β. If $\alpha = \beta = 1$ a uniform distribution is obtained. For α and $\beta > 1$ a unimodal distribution with a mode at M where

$$M = \frac{\alpha - 1}{\alpha + \beta - 2}$$

is obtained. This is a symmetric distribution with $M = 0.5$ if