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Beyond Hypothesis-Testing: using Approximate Bayesian Computation for comparing multiple models of cultural transmission in Neolithic Europe.

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The current renaissance of computer simulation in archaeology is showcasing a wide array of successful applications where archaeological theory-building is formalised, and existing methods are evaluated and refined through "tactical" simulations (Lake 2010). However, hypothesis-testing continues to suffer the difficult task of comparing simulation outputs against empirically observed archaeological data. The mathematical rigour used in statistical science is hardly applied in many cases, and simulation models are often evaluated exclusively in visual and qualitative terms. Moreover, the ultimate objective is often not the rejection of a null model, but to evaluate the goodness-of-fit of a purposely designed archaeological model. Whilst this approach has undoubtedly yielded a useful basis for further theory-building through the assessment of mismatches between the artificial and archaeological data, it does not question whether alternative models that can equally, or even better, explain the observed pattern that exists. Such a multi-model approach is beginning to be used in the evaluation of competing statistical models in anthropology and archaeology through the epistemological framework of information-criteria (e.g. Beheim and Bell 2011, Eve and Crema 2014). Similar approaches in agent-based simulation are however still uncommon (but see Piou et al 2009).

Here we illustrate an alternative way to incorporate a multi-model approach based on Approximate Bayesian Computation (ABC, Csilléry et al 2010), a simulation-based methodological framework that was originally developed in population genetics (Beaumont et al 2002). Given one or more simulation models capable of generating summary statistics S, a prior estimate of the model parameters, and an observed target data described by the same summary statistic S, ABC can provide: 1) posterior estimates of the parameters of each model; and 2) numerical indices (e.g. Bayes factors, Deviance Information Criteria) indicating which model has the best fit to the data with the smallest number of assumptions.

We illustrate the application of ABC in archaeology by examining two case studies in Neolithic Europe: armature assemblages from the Clairvaux and Chalain sites in southeast France and pottery decorative styles from the Merzbach valley in western Germany. In both cases our primary objective is to assess different modes of cultural transmission by examining temporal changes in the frequency of cultural variants. This follows a long-lasting research agenda spanning almost two decades and showcasing a wide variety of case studies and methods (Neiman 1995, Shennan and Wilkinson 2001, Kohler et al 2004, Mesoudi et al 2008, Kandler and Shennan 2013) as well as critiques and limitations (e.g. Steele et al 2010, Premo 2014).

For the purpose of this paper we formalized three models of cultural transmission: 1) an unbiased transmission model; 2) a frequency-bias model which includes both anti-conformist and conformist transmission biases; 3) and a retention- bias model, where agents have a higher chance of retaining traits that they already possess. By translating the mathematical models into agent-based simulation we were also able to integrate archaeological biases such as the effect of time-averaging and differential sample size, overcoming some of the most recent critiques (e.g. Premo 2014).

Our results highlight both the limits and the potential of this approach in archaeological contexts. On the one hand, ABC successfully indicated that retention bias and anti-conformist bias are respectively the best models for the armature and pottery data. The posterior distribution returned probabilistic estimates of the model parameters, providing a better picture on the possible processes behind the observed archaeological pattern. On the other hand ABC highlighted known limits of a simulation-based analysis of archaeological data: the choice of suitable and sufficient summary statistics to describe the observed data, and the limits imposed by the problem of equifinality. ABC, however, offers the possibility of quantifying these shortcomingss, and hence we believe this is a promising venue for a more empirically grounded model-based archaeology.

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