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Final Paper Humans and their Environments

Reproducibility in Archaeological Discoveries

Peer review is a critical process for any scientific discovery. When a researcher produces a paper containing their work, the paper is then scrutinized by other professionals in the same field before it is published. This process exists to help verify that the new discoveries are the production of rigorous and methodical work, and that the facts and conclusions presented by the paper are sound.

In hard sciences, like mathematics or chemistry, it is usually clear what steps are necessary to follow to verify a given discovery. For mathematics, derive a proof for whatever new relation was discovered. In chemistry, reproduce whatever new reaction was found.

In archaeology, the steps necessary to reproduce a given discovery are nowhere near as obvious. When an archaeologist discovers some new facet of an ancient civilization through an excavation, ideally one of their peers could return to the site and perform the same excavation. Alas the very nature of an excavation is to irreparably destroy the site, not to mention the time, money, manpower, and organization required to perform an excavation.

Despite the impossibility of perfectly reproducing an excavation, the analysis that takes place on the artefacts and measurements obtained during the excavation has no such restriction. So long as the data recovered from excavations is assumed to have been produced truthfully and with rigorous techniques, archaeological discoveries should thus be reproducible through inspections and reconstructions of the analysis performed.

Unfortunately the majority of published archaeological papers don't make their datasets available, and those that do often fail to sufficiently document the decisions made in the transformations and analysis of the data.

In January of 2016 Ben Marwick published a paper titled "Computational Reproducibility in Archaeological Research: Basic Principles and a Case Study of their Implementation" [1]. In this paper he borrows some tools from the field of software engineering in an attempt to address this issue, and ultimately outlines four principles that could be applied to archaeological research to improve reproducibility. This paper will outline and detail these principles, identify their impact on a case study on their implementation done by Marwick, and attempt to identify and address issues with their widespread adoption in the field.

These principles are as follows: to publish the datasets collected for the research, perform analysis on these datasets with computer scripts, use version control to help manage the files in the project, and to provide a consistent computational environment to guarantee that the scripts will be usable in the future.

The first of these principles, to publish the datasets developed during the research, requires little planning or additional background knowledge, and consideration of this may even be deferrable until after publication of the research. This principle will also result in the largest rewards of any of the principles, as Marwick enumerates many studies which have shown that papers that make their datasets available enjoy higher numbers of citations.

The second of these principles, to perform analysis via computer scripts, stems from a handful of reasons. Scientific research in general has been trending towards using computation to perform analysis, and archaeology is no exception. Unfortunately graphical user applications like Excel do not lend themselves well to reproducibility, as recording a series of operations (e.g. button clicks) isn't particularly easy and the user interfaces will change over time. A script on the other hand records the steps it performs by its very nature; a script is a list of steps for the computer to perform to carry out the analysis. There are also quantifiable benefits to individual researchers for doing computation through scripts, as they benefit from freely available code produced by other researchers.

The third principle doesn't directly improve research reproducibility, and instead exists as advice to simplify project management. Version control software is a tool commonly employed by software engineers, and allows changes to files to be tracked and accounted for. Using such a tool allows access to the state of the project at any point in time. If the scripts are discovered to have broken due to some change, it is easy to simply restore a previous version of the script before the harmful change was introduced.

The fourth principle, to provide a consistent computational environment, lacks quantifiable benefits to the researcher but will assist their peers in reproducing their work. This has traditionally been done with virtual machines, but lately a more practical tool referred to as Linux containers has been gaining popularity among software engineers.

These principles were applied during a paper that Marwick assisted in producing. Focusing on a site in northern Australia called Madjedbebe, the authors performed an analysis on stone and faunal artefacts obtained during an excavation in 1989. The objective was to verify the stratigraphic integrity of the original excavation and corresponding analysis, which demonstrated that the site had human occupation between 50 and 60 thousand years ago [2].

This paper does briefly mention that the analysis and visualization of the data was performed with R scripts, and provides a URL to where the data and source code can be accessed. Aside from the short mention of these methods before launching into a presentation of the results, the paper doesn't otherwise discuss or mention the computational approach to analysis.

In Marwick's paper on reproducibility, he describes what tools he used in the Madjedbebe study to accomplish each of his four principles. To publish the dataset he used Figshare, which provides file hosting services tailored specifically for academic research. Figshare is not specific to archaeological research, and there are online services that are, but Figshare provides free unlimited archiving of any file type, so long as each file is less than 250 MB in size.

To achieve his second principle of performing analysis with scripts, Marwick used the programming language R. This language is popular among researchers in various other disciplines, and is heavily geared towards data analysis and visualization. Notably the language is used extensively among statisticians, which has the nice result of a wide selection of statistical algorithms freely available in the language.

As for version control and a consistent computational environment, git and docker were respectively chosen. Both have the benefit of being widely used by software engineers, and thus have extensive documentation and there exist services that will freely host git repositories and docker images.

Marwick also discusses the practicality of a typical archaeologist using these technologies. To do so, an archaeologist must become proficient in both programming and related tools. Marwick states that he spent 3 years teaching himself how to use R, which is probably a time commitment most archaeologists would balk at (that's over half the time it takes to get an undergraduate degree). Even were an archaeologist to invest the time to learn these tools, one issue Marwick faced was a very uneven distribution of work among the researchers in the Madjedbebe study. Those more familiar with R were much more heavily involved in the final analysis than those who were less capable with the tool.

Fortunately, 3 years is likely a much longer time than is necessary to develop a familiarity with R. Marwick himself suspects that that competence could be developed "substantially quicker" than 3 years by taking short training courses. There are already multiple organizations offering such courses, like Software Carpentry and rOpenSci. Marwick also holds the opinion that once the technologies are learned, applying them will take no longer than alternative techniques and may even offer some time savings due to the fact that code produced by past efforts is often reusable.

Even if training archaeologists to program was trivial, realistically any processes to address reproducibility won't be adopted without a mandate, presumably from the journals. Luckily the discipline has already demonstrated it can quickly adopt new processes when necessary, as happened roughly a decade ago.

In 2006 Grimm et al. published "A standard protocol for describing individual-based and agent-based models", which outlines a standard protocol for the presentation of research based on agent-based modeling. This was the ODD protocol, which is an acronym for Overview, Design concepts, and Details [3]. Since the publication, this protocol has been widely adopted by many disciplines, archaeology included. Organizations like OpenABM have even appeared to support this process.

Were other processes to be standardized and imposed on archaeologists, in the name of reproducibility, the adoption of the ODD protocol shows that they can be accepted by the discipline.

As a specific requirement for journals to impose on researchers, Marwick suggests that a research compendia be required alongside any paper presented for publication. Such a compendia would include at a minimum the manuscript and dataset produced during the research, and potentially also files such as the suggested scripts to perform analysis on the data.

To explore a practical application of these concepts, I sought to find an archaological paper that has a published dataset, and aside from this has not adhered to any of the other principles outlined by Marwick. With the paper and dataset, I would create a script that would ingest the published dataset and programmatically reproduce a subset of the analysis performed by the paper.

After a brief search, I found a paper titled "Food for Rome: A Stable Isotope Investigation of Diet in the Imperial Period (1st-3rd Centuries AD)" that utilizes a dataset published on figshare.com [4].

This paper performed a stable isotope analysis on skeletons found in cemeteries around Rome, Italy dating back to the 1st to 3rd centuries AD. The analysis aimed to establish if there were differing diets between non-upper-class members of ancient Roman society based on varying factors like gender and urban vs suburban environments.

The cemeteries sourced for skeletons were Casal Bertone, which was very close to the city of Rome, and Castellaccio Europarco, which was close to the edge of the 50 km radius that defined the suburbium around the city. In Castellaccio Europarco, the skeletons were also divided between a necropolis and a mausoleum, with the mausoleum samples likely belonging to what were wealthier individuals in ancient Roman society.

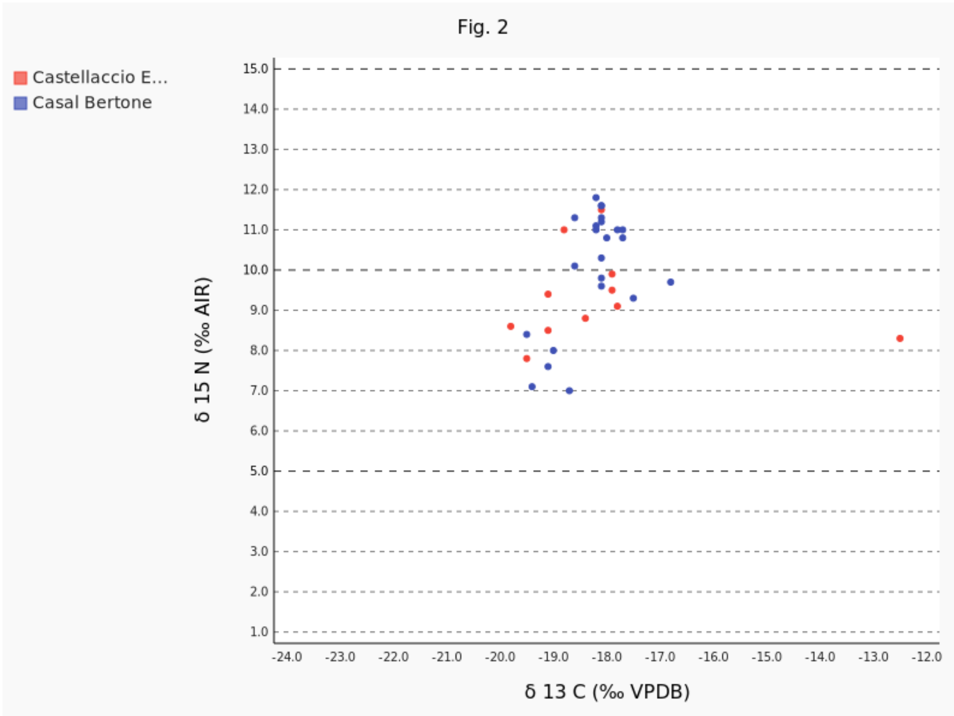
Based on the analysis performed by the authors, they found that individuals from an urban environment (the skeletons from Casal Bertone) favored aquatic foods, while individuals from a more suburban environment ate much more millet-based foods. There were no discernible differences in diet between the genders.

I decided to attempt to reproduce figure 2 in the paper, which graphed the carbon isotopes versus the nitrogen isotopes on a scatter plot for skeletons from both locations. My objective was to use a script written in Python to read in data from the excavation and produce an image of the graph in the figure.

In order to attempt to reproduce this graph, I of course needed the data, which I downloaded from figshare. I however immediately encountered an issue with my plan, as the data was stored in a .mdb file, which is the format used by Microsoft Access. As I don't have Microsoft Office, it took quite some time to figure out how to access this data. Python has tools to read data out of a Microsoft Access file, but these tools only work when run on a Windows computer, whereas my laptop is running Linux. After much searching for a tool, I managed to write a Python script that, when combined with an external tool on Linux, was able to export the data into CSV files.

This little adventure in being able to get the data into a format I could work with was very interesting, as Marwick does mention that when data is published it is ideally made available in an easy to use format, and calls out CSV specifically as a good format. The idea behind his suggestion is that if your data can't be viewed by the reader, its usefulness is greatly reduced. Microsoft Access files are not portable at all, and will only be readable on Windows machines, whereas the CSV format is supported on a myriad of systems (Microsoft Excel included) [1].

With the data in CSV, I wrote a Python script that reads in one of the tables, filters out all rows that don't include values for every necessary field for the graph, and then saves out a PNG file with the graphed data. This is the resulting graph:



A programmatically generated version of figure 2 from "Food for Rome" [4].

Missing from the graph is all of the data points from the animals, and there's no distinction between samples from the mausoleum and the necropolis in Casal Bertone. The table in the published dataset that I used to produce the graph included no data on animals, and the table made no distinction between the two locations for skeletons from Casal Bertone.

Aside from the missing datapoints, the graph does exactly represent figure 2 from "Food for Rome". By inspection of the code that generates the graph, which should be a fairly trivial process for someone familiar with Python as the script in its entirety is 25 lines, it's clear how the graph is produced from the dataset.

I would also liked to have reproduced figure 4 from the paper, as it features distinct groupings of points that are visually recognizable, and clearly demonstrates a notable difference between the groups, I decided not too as I did not know the values for the protein lines plotted on the graph.

For all of the situations in which I did not know the source of some of the data in the graphs presented by the paper, the animal data in figure 2, the distinction between the skeleton locations from Casal Bertone in figure 2, and the values for the protein lines in figure 4, my answers would have been easily discoverable had the graphs been produced by auditable scripts. In the current state of affairs, I do not know how the graphs are generated and where or how the data I am lacking in my graph comes from.

The python script used for this paper, in addition to the source for my paper itself, is available at `https://github.com/dgonyeo/humans-and-their-environment`.

This application of Marwick's principles hopefully illustrates the benefits of programmatically performing one's analysis, as multiple aspects of the graphs "Food for Rome" presents would have been much clearer to me had there been a script that would generate the graphs.

References

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