Introduction

I am not an archaeologist. I am a computer scientist; what I lack in knowledge of pottery sherds and lithics I make up for in knowledge of things digital. And there is a storm coming.[1]

Currently the Internet Archive, a major aggregator of digital content, contains 60 million items—effectively, digital "artifacts." Only a year ago it held 45 million, and next year it will have millions more. Some of these artifacts will be items from other forms of media, newly digitized, and some will have been born digital. The Internet Archive sees just a small fraction of what actually exists in digital form, of course, and yet even in this one sampling it is clear that there is a staggering amount of material.

Why does this matter? Traditionally, archaeology has sought to understand humans through their material culture: things that people created, or affected, and things that in turn affected them. Through that lens, *a digital artifact is an artifact*. A digital artifact is the product of human ingenuity and creativity, one that affects the course of human lives. Much of modern culture is expressed in digital form, and this trend is increasing. To remain relevant in the modern world, archaeology must make sense of contemporary artifacts in a meaningful, knowledgeable way. Without exploring digital artifacts, we are effectively and willfully experiencing amnesia.

As an outsider versed in digital technology, I am naturally biased, but this external, independent vantage point also allows me to observe and critique archaeological efforts to study the digital. Digital archaeology and computational archaeology are a good place to start: their names sound promising, but they are areas staunchly committed to the notion of using computers and computation to understand the old rather than to examine the new. To exemplify the problem, we need look no further than the international organization Computer

Applications and Quantitative Methods in Archaeology (CAA), one of whose stated goals is "to encourage communication and collaboration" between, amongst others, archaeologists and computer scientists (n.d.: item 2). Yet the CAA's *Journal of Computer Applications in Archaeology* considers only "a wide variety of topics in digital applications *to* archaeology" (n.d.: para. 2—emphasis added): computers in servitude. While the use of the computer as a tool to advance traditional archaeology is laudable, this narrow definition of digital applications inhibits their value for comprehending the contemporary. Even a discussion of "grand challenges" for digital archaeology (Huggett, Reilly, and Lock 2018) fails to consider that the relationship between archaeology and the digital can be much more than an inwardly focused affair.

One might object that the study of digital artifacts aligns with so-called media archaeology rather than archaeology proper. This is incorrect for two reasons. First, media archaeology has declared, in no uncertain terms, that it is not archaeology (Huhtamo and Parikka 2011: 3). Second, the stated scope of media archaeology explicitly omits the possibility of an overlap with science and engineering (Huhtamo and Parikka 2011: 3), the very fields necessary to help make sense of digital artifacts; certainly, media archaeology's lack of a clear methodology has seen harsh criticism (Elsaesser 2016). As much as archaeology might wish to abdicate digital artifacts to media archaeology, this critical piece of contemporary culture cannot and should not be outsourced. Indeed, Finn argues for the archaeological importance of being able to see "technological evolution over years and decades, rather than centuries or millennia" (2013: 657).

If there is no agreed-upon home for the study of digital artifacts within archaeology, we can instead examine specific pieces of research that seek to understand these artifacts. Moshenska (2014), for example, recounts the discovery of a buried USB flash drive during a school-outreach excavation. Approaching it initially as a physical artifact, he applied conservation techniques, then addressed its digital content by plugging the still functional drive into a computer. This revealed predominantly music and video files, along with a smattering of schoolwork. While a deeper dive into the flash drive's digital strata would have been possible with the appropriate equipment and software, the point of the exercise is well made: digital artifacts can be viewed in an archaeological manner.

Perry and Morgan continue in this vein, noting the absence of "a robust research process and an adapted methodological toolkit" (2015: 96) for handling digital media. One of their key contributions was an attempt to formally record the "strata" they encountered—

both physical and digital—when examining a hard drive and its contents, although they stopped short of computer code "excavation," rightly believing it to be a necessary but nontrivial undertaking. A vital but understated point in their work is the transition made in their investigation from nondestructive to destructive processes (2015: 97); the digital work took place prior to that transition. A digital artifact is a site that can be excavated in a nondestructive way, far removed from Barker's characterization of excavation as "an unrepeatable experiment" (1993: 13). This opens the door to an archaeology that is reproducible and verifiable by others: cornerstones of the scientific endeavor.

Even archaeology itself can leave digital artifacts to study. Reilly, Todd, and Walter (2016) tell the fascinating story about some early archaeological computer modeling work in the mid-1980s, visualizing the Old Minster in Winchester, UK. Presumed lost, the model's files were rediscovered by chance some thirty years later and converted into a modern format. This afforded the opportunity not only to render them in new ways (e.g., 3D printing), but also to reflect on the original project in view of newer developments in cultural heritage, such as the London Charter that outlines best practices for computer visualization (Denard 2016). While this particular story had a happy ending, it does emphasize the reality that digital artifacts do not necessarily persist forever, and that they may be far from "future proof" when content is locked into proprietary or now-obsolete formats.

As as outsider to the field, a striking facet of the type of archaeological work that studies digital artifacts is how little of it there is compared to the volume of digital material we are generating. Why is there such an aversion to digital artifacts within archaeology when we are awash with them and when they are so central to our contemporary lives? Will archaeologists in one- or two-hundred years lament that the field of today not only failed to engage with these ephemeral artifacts, but also failed to lay down groundwork to train new generations of archaeologists in how to deal with them?

There is, however, a relatively new area of study within archaeology that has been actively working to fill this vacuum: archaeogaming. Reinhard (2018b: 2) defines this as "the archaeology both in and of digital games," observing that its earliest threads stretch back to 2002 (Watrall 2002). More recently, Graham (2020) has contextualized archaeogaming by drawing a connection to agent-based modeling: for Graham, the archaeogaming he practices allows archaeologists/players to be participants in a simulation model. This is one of many understandings of archaeogaming.

While it may seem counterproductive to restrict the scope of digital artifact study to games, or frivolous to study digital games at all, there is a compelling case to be made. The video game industry is enormous, a multi–billion-dollar global affair (e.g., Entertainment Software Association 2019; Entertainment Software Association of Canada 2019; TIGA n.d.) rivaling or surpassing, by some estimates, the traditional entertainment industry. At that size, the game industry can't *not* be influential on society and culture. Admittedly, financial statements may not be the best metric, but it is much harder to argue with the sheer numbers who play these games, constituting a convincing proportion of the population (Entertainment Software Association 2019; Bankhurst 2020; TIGA n.d.). Really, it should come as no surprise that humans play games—evidence for play stretches back to Neolithic times (Rollefson 1992)—and it makes sense for archaeology to study modern as well as ancient games. Furthermore, a focus on games maximizes the overlap with allied nonarchaeological fields of study, including game studies, platform studies, game history, and computing history.

Archaeogaming as practiced is notably inclusive in terms of the topics that fall under its umbrella. Most familiar might be examples where the games themselves are treated as physical artifacts to be recovered by excavation: a longstanding urban legend, for instance, was that Atari had buried game cartridges in a New Mexico landfill site in the early 1980s, a story verified by excavation in 2014 (Reinhard 2015).

From physical to virtual, as locations of human activity, we can treat game worlds as virtual sites and adapt archaeological techniques to study them. The 2016 game *No Man's Sky* offered its players an enormous, effectively infinite, procedurally generated universe to explore. In response, the *No Man's Sky* Archaeological Survey was formed to document machine-created culture (Reinhard 2018b), followed thereafter by the Legacy Hub Archaeological Project, which aimed to record human in-game material cultural remains following a cataclysmic event in the game universe (Reinhard 2019). Such in-game work, whether single- or multiple-player, additionally necessitates considerations of how it can be conducted ethically (Dennis 2016; Flick, Dennis, and Reinhard 2017)—considerations that extend to digital archaeology in general (Dennis 2020).

The content of games can also be studied in archaeogaming. We see, for example, surveys of how archaeology and archaeologists are represented in video games, highlighting inaccurate portrayals as well as the need to address them, because "to deny the power of [Lara] Croft and [Indiana] Jones in encouraging young archaeologists would

be futile" (Meyers Emery and Reinhard 2015: 144). By contrast, Copplestone (2017) advocates taking control of the video game narrative in order to create games that communicate and help critically reflect on the archaeological process.

While these brief examples illustrate the breadth of archaeogaming work, they do not explore the implementation of the games, the technology that brought these digital artifacts to fruition. Fortunately, archaeogaming is not lacking in this regard. Extending Perry and Morgan's aforementioned 2015 work, Reinhard (2018a) has experimented with expressing software versions of *No Man's Sky* in a Harris matrix. He later undertook an extensive archaeological study of the source code for the early text adventure game *Colossal Cave* (Reinhard 2019). In collaborations with archaeologists and others, I myself have conducted archaeogaming research into the implementation of copy protection (Aycock and Reinhard 2017) and full-motion video (Aycock, Reinhard, and Therrien 2019), along with in-depth examinations of single games (Aycock and Copplestone 2019; Aycock and Biittner 2019) and entire game corpora (Aycock and Biittner 2020). Digital artifacts can be individually examined, and with the right tools, they can be studied en masse.

It is instructive to examine the reasons why we have yet to see more technical work with digital artifacts, either in archaeogaming or in archaeology more generally. The above phrase, "collaborations with archaeologists," is key. Both archaeology and computer science are full-time pursuits, and it is only by combining forces in an interdisciplinary effort that these digital artifacts can be thoroughly examined. This echoes one of Moshenska's conclusions following his flash drive study (2014), and represents a natural extension of how archaeologists increasingly work with specialists in other subject areas, except here looking to apply archaeology to computer science, not the other way around. However, there are systemic issues outside archaeology that affect collaborative opportunities. Computer science, for example, glorifies the new and novel with relatively little consideration of the past. Or, as historian Thomas Haigh puts it, "the technical history of computer science is greatly understudied" (2014: 43).

It is heartening, though, that computer scientists and archaeologists follow some similar methodologies. Moshenska (2016) has explored how the reverse engineering of technological artifacts and contemporary archaeology are intertwined, and in lieu of a game's source code—which is often inaccessible—reverse engineering the binary code of the game is exactly the path a computer scientist would take. This is a specialized skill in computer science, albeit an important

one, because it is used extensively in the computer security industry to analyze malicious software, such as computer viruses and worms. The process of reverse engineering a video game can even be considered to parallel Carver's "field research procedure" (Carver 2009): reconnoitering to select a site (a game); preliminarily evaluating the game using extant software tools; planning strategy and defining research questions; excavating via reverse engineering to address those questions. In many ways, we are not so far apart.

In the time it has taken to read this section, the Internet Archive has added an average of several hundred new digital items to its trove. What a wonder it would be to discover that many physical artifacts in the same amount of time during an excavation! Digital artifacts pose enormous challenges but also enormous opportunities. Archaeology should be at its forefront.

Fetch the Torches and Pitchforks

The preceding text appeared as a debate article in the journal *Antiquity* (Aycock 2021a) and, as part of that process, three responses were solicited (Huggett 2021; Whitcher Kansa and Kansa 2021; Morgan 2021), and I was allowed the last word (Aycock 2021b). I was unsure what the reception would be, as a foreigner to the land of archaeology, and whether I would even be smart and well-read enough to understand these responses from experts in a wholly other field. Obviously there were minor quibbles, such as my abbreviated characterization of digital archaeology (Huggett 2021), and questioning what new perspective archaeology could bring to the discourse on digital artifacts (Huggett 2021; Whitcher Kansa and Kansa 2021). Yet there were also clear points of agreement, both acknowledging the uncertainty in extending beyond the bounds of traditional archaeology (Huggett 2021) while asserting that "archaeology can and should be more than a consumer of the outcomes of computer science" (Whitcher Kansa and Kansa 2021: 1,596). What struck me the most is that we all agreed on the need for archaeology of the digital, but that this archaeology looked different for each of us. The range was notable: bigger-picture, systemic concerns about digital technology (Morgan 2021); "data literacy" and digital artifacts generated from within archaeology (Whitcher Kansa and Kansa 2021). And, of course, my own computer-science-centric view, understanding the workings of digital artifacts.

There are also connections between the argument in the previous section and nondigital matters within archaeology.[2] For example,

Perry (2019) posits a future for archaeology wherein "enchantment" results in inspiring public consumers of the archaeological record into positive action; this can be viewed as arguing to give archaeology an increased modern-day relevance. Goading archaeology into broader engagement with digital artifacts has an end goal that is not dissimilar, and in fact it is not incompatible with Perry's approach.

Work on digital artifacts also adds fuel to the discussion over whether objects have agency (Hoskins 2006). With any computer-based artifact, but particularly with highly interactive software like video games, the object is operating apart from its creator in a very visible, tangible way. The agency of objects in the video game context is much easier to imagine than it would be for a static, inanimate physical object. At the same time, reverse engineering a digital artifact arguably makes the case against agency equally well, because it allows us to peer behind the veil to reveal the artifact as a clever artifice of human endeavor.

At any rate, no vexing questions pertaining to archaeological thought will be settled within these pages because, again, I am not an archaeologist. What I *can* do, however, is deliver on a promise to "document, in an accessible fashion, the techniques and thought processes I use when analysing digital artefacts" (Aycock 2021b: 1,600).

About This Book

In front of me is a copy of Martin Carver's book *Archaeological Investigation* (2009), its pages bristling with yellow sticky notes. Carver delineates field archaeology as a six-step process: reconnaissance to locate a likely site, site evaluation, and strategy (excavation planning and choosing research questions), followed by excavation, analysis of the results, and publication. To back up my frivolous assertion above, that reverse engineering a video game parallels Carver's process, the remainder of this book illustrates and explains the reverse engineering of the 1986 game *Amnesia*. I will be following Carver's Field Research Procedure as a guide, and the organization of the book reflects this. The book is divided into three parts—pre-excavation, excavation, and post-excavation—with the majority devoted to the reverse engineering, the "excavations" I will be performing.

Doubtless to the dismay of trained archaeologists, I will be using the terms "site" and "artifact" interchangeably to reflect the reality of digital excavations. On the one hand, *Amnesia* seems like a discrete artifact, with a physical manifestation that can be held in the hand and

a digital image that corresponds to the game. On the other hand, this is a superficial view, because the digital form of *Amnesia* is a multilayered site with many diverse parts and locations into which we can dig, and *Amnesia* is not unique in this respect. It is simply digital.

I am starting my examination of the *Amnesia* artifact-site with no special information. I do not possess a copy of the human-readable source code that the programmers of the game wrote, only the ones and zeros present in the binary image of the game that was published decades ago. Everything that will be revealed about this binary image will be learned through reverse engineering, the gradual process of reconstructing the knowledge that went into *Amnesia*'s creation. A reverse engineer is a puzzle-solver and detective, roles archaeologists are well used to playing. What makes reverse engineering of computer code particularly exciting and challenging is that the site is alive in a sense. We are not simply staring at a static, lifeless pottery sherd sitting in the dirt, imagining what it might have been part of and how it was used, although studying (fragments of) code and data is certainly one technique a reverse engineer might employ. Instead, we often have the option of observing the code as it runs and watching the data as it is used. In other words, we can view the sherd as a part of the whole pottery from whence it came, see the context in which that pottery was used, even ask and answer questions about what might happen at this site if the pottery were crafted somewhat differently. As if this ability were not magical enough, there is more to digital artifacts that might seem straight from the pages of *Harry Potter*: the data *and even the code* may change as the game's code—the instructions for the computer to perform—runs. Reverse engineering binary code is solving a puzzle where the puzzle pieces can move and transform themselves before our eyes.

Reverse engineers are not only puzzle-solvers and detectives but may be toolsmiths as well. Nominally, building tools might be considered akin to experimental archaeology; here, the purpose is not only to demonstrate the plausibility of hypotheses but to create bespoke software tools that amplify our ability to analyze a program. The suggestion of forging software tools may strike fear into the hearts of archaeologists with little or no programming experience, a reasonable apprehension. However, remember that the study of digital artifacts can and should be an interdisciplinary endeavor, and the archaeologist may not be the one creating such tools. The critical takeaway here is understanding when and why new software tools may be necessary, and what benefits they might offer.

Toolsmithing aside, archaeologists and other non–computer science readers may find parts of this book to be a challenging read. A number

of technical details are needed to perform and comprehend binary reverse engineering, and as a result this book contains a variety of tutorial background information about necessary computer science concepts, a crash course that will permit archaeologists to begin their own meaningful examinations of the digital. I should also point out that what I am about to describe is not the only way to reverse-engineer *Amnesia*, and I have tried to show a variety of techniques, not all of which may be needed for a given artifact. Using different (existing or novel) software tools may also make the reverse engineering process easier or harder, although ultimately the underlying principles and thought processes remain the same and are possible to learn. Let us begin.

Notes

1. The initial part of this chapter was first published as Aycock (2021a) and appears here with minor modifications. The original article is © John Aycock, 2021, and is reprinted with permission. The acknowledgments for that article read: "Thanks to Jason Scott at the Internet Archive for supplying the statistics. Katie Biittner and Andrew Reinhard provided insightful comments on a draft of this article, and the anonymous reviewers made many helpful suggestions. The author's work was supported in part by the Natural Sciences and Engineering Research Council of Canada, grant RGPIN-2015-06359." I am also grateful to the *Antiquity* editors for their superlative editing of the article.
2. I am grateful to an anonymous reviewer of the book draft for this observation and other suggestions for this section.

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