The Apparatus of Digital Archaeology

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Abstract
Digital Archaeology is predicated upon an ever-changing set of apparatuses – technological, methodological, software, hardware, material, immaterial – which in their own ways and to varying degrees shape the nature of Digital Archaeology. Our attention, however, is perhaps inevitably more closely focussed on research questions, choice of data, and the kinds of analyses and outputs. In the process we tend to overlook the effects the tools themselves have on the archaeology we do beyond the immediate consequences of the digital. This paper introduces cognitive artefacts as a means of addressing the apparatus more directly within the context of the developing archaeological digital ecosystem. It argues that a critical appreciation of our computational cognitive artefacts is key to understanding their effects on both our own cognition and on the creation of archaeological knowledge. In the process, it defines a form of cognitive digital archaeology in terms of four distinct methods for extracting cognition from the digital apparatus layer by layer.

1. Thinking about things
Although it is increasingly recognised that the tools we use to examine our objects of study change our relationship to them, this is not an area that has been studied in any great detail within Digital Archaeology beyond perhaps discussions of the effects of different categories of software (the impact of GIS or database applications, for instance, or the effect of enlarged access to open data sources) on how we organise and understand the past. I have suggested elsewhere that through understanding how these technologies operate on us as well as for us, we can seek to ensure that they serve us better in what as archaeologists we already do, and help us initiate new and innovative ways of thinking about the past (Huggett 2004, 2012a). This entails going beyond the relatively commonplace reflections on specific software applications and their context of use: the tools we create, adopt, refine and employ have the effect of augmenting and scaffolding our thought and analysis, and consequently I have argued that they need to be approached in a considered, aware, and knowledgeable manner.

One of the key transformations in archaeological studies in the past thirty years is the shift from analogue to digital. In archaeological survey, for instance, we have witnessed a move from analogue tapes and dumpy levels to digital total stations and electronic distance meters which employ built-in algorithms to capture, record and process data through a mixture of semi-automated and fully automated methods. We have seen the cost of terrestrial laser scanners come down in recent years, and, perhaps more significantly, the development of the SIFT (Scale Invariant Feature Transforms) algorithm has seen an explosion in the use of structure from motion photogrammetry as a means of three-dimensional survey using consumer-grade cameras and drones. In the process, we have witnessed changes to the way in which we see the world and capture what we see. Much the same story might be told about other toolsets – whether we think of the developments in geophysical survey, for instance (see Ferraby, this volume), or the expansion of digital photography (for example, Morgan, forthcoming), or the growth of digital archives. But in each case, what do the changes in perspective offered by these tools imply for the practice of archaeology? And, as importantly, what are the implications of the development and use of these tools themselves?

The fact that archaeologists have been largely content to benefit from the application and contribution of these digital tools and have not paid a great deal of attention to these questions is far from unique. For example, until recently most philosophers of science focussed on the theories surrounding scientific knowledge rather than the instruments that were employed in laboratories or elsewhere (for example, Bunge 2010, 85). Similarly, Ian Hodder has argued that archaeologists need to look more closely at things themselves:

> "As social actors we tend to see things in ego-centred ways, in terms of what they can do for us. We hardly look at them. Our interests are in the effects for us, aesthetic, social, scientific, psychological and so on. But every now and then we actually look at the thing itself, as a whole object, a thing in its own right … there is sometimes a moment of realization that in order to understand the thing we have to look harder, anew, deeper, more fully." (Hodder 2012, 2)

Here Hodder is interested in 'things' in the widest possible sense whereas I am thinking in rather narrower, digital, terms. However, as he goes on to say,

> "… what makes an object relevant and useful in relation to the production of scientific knowledge … is not just the object itself, but the knowledge involved in recognizing an object for what it is and how it can be used." (Hodder 2012, 3)

and he adds that there is also knowledge incorporated within the object itself, in the form of knowledge about measurement procedures, physical properties and so on. We might add to this list the embedded algorithms used to capture and manipulate data, for example.

The expanding development of autonomous cars and other forms of data-driven artificial intelligence (AI) has resulted in a lot of discussion about the benefits and risks associated with apparently knowledgeable machines in society more generally. In this context, however, AI devices are only one small group of things which incorporate and use knowledge for our benefit. At the other extreme, some philosophers of science – and indeed, Hodder himself – would argue that knowledge is encapsulated in even the most basic artefact. Hence, for example, the archaeological trowel contains knowledge in the form of its design, the relationship between handle and blade, etc. (albeit characteristics determined by a different domain), and through its application it reveals knowledge of archaeological value. If we doubt the complexity inherent in the trowel, consider that its mode of practice has to be adapted to the soil conditions and its use is not self-evident to the novice, nor does any written description of its operation substitute for direct demonstration and hands-on experience.

2. Cognitive artefacts

However, a rather more limited range of devices are of interest here. These may be characterised as 'cognitive artefacts': human-made physical objects which we employ as a means of assisting us in performing a cognitive task, and which are able to represent, store, retrieve, and manipulate information (e.g. Norman 1992; 1993). The digital 'cognitive artefacts' that archaeologists use – for example, digital cameras, total stations, laser scanners, proton magnetometers, X-ray fluorescence machines, and their ilk – all encapsulate in various ways a mixture of techniques, calculations, and interventions which they employ on our behalf to explore, reveal, capture, and characterise archaeological objects. These cognitive artefacts support us in performing tasks that otherwise at best we would have to conduct using more laborious and time-consuming methods (film photography or measured survey using tapes, for instance) or that we would not be able to undertake (we cannot physically see beneath the ground, or determine the chemical constituents of an object, for example). Furthermore, a characteristic of archaeology is the way that we adopt and apply tools and techniques developed in other domains (Schollar 1999, 8; Lull 1999, 381). Consequently, most if not all of the cognitive artefacts used in archaeology are designed outside their discipline of application, meaning we have little or no control over their development and manufacture, and hence their internal modes of operation have to be taken at face value.

As a result:

> "Cognitive artifacts are … important to study, not only because they make us more powerful and versatile thinkers, but also because they shape and transform our cognitive system and cognitive practices" (Heersmink 2013, 466).

Hodder would seem to agree in relation to things in general:

> "Humans have had increasingly to invest labour and new technologies to manage and sustain these things and have found themselves organized by them … Indeed it could further be argued that humans become regulated and disciplined in their interactions with things in all their complexities and falling-apart uncertainties." (2012, 86).

These effects make it all the more important to investigate and understand the digital tools which we employ in our discovery, capture, and exploration of the past.

3. Digital cognitive agency

In philosophical terms, discussion of cognitive artefacts is linked to contested debates concerning the extended mind theory, distributed cognition, and extended perception. Within archaeology, they are also closely associated with dialogues surrounding cognitive archaeology, neuroarchaeology, and agency more generally.

Cognitive artefacts may be seen in terms of functioning in a similar fashion to the equivalent human cognitive process. This is the basis for seeing computer reasoning as a model of the human mind, for instance. Clark and Chalmers (1998) argued that a proportion of a cognitive task could be conducted outside the human mind through linking the human agent in a two-way interaction with an external entity to create a coupled cognitive system. This external cognitive process is seen as an extension of the human mind through what Clark subsequently defined as the *parity principle* (2005, 2). This considers that if a function undertaken by an external device would be considered to be cognitive if performed by the human mind, then that device is functionally part of that extended cognitive process; hence:

> "if an inner mechanism with this functionality would intuitively count as cognitive, then (skin-based prejudices aside) why not an external one?" (Clark 2005, 7).

This definition of the parity principle is not uncontested (see Menary 2007, 55ff, for example), since, for instance, it seems to allow for things to think independently in what Sutton calls uncoupled material-cognitive agency (2008, 40). Nevertheless, some archaeologists have built on Clark's model of the extended mind and parity principle. For example, in his development of a neuroarchaeology of the mind, Malafouris emphasises the importance of material culture in understanding human cognitive evolution:

> "The extraordinary projective plasticity of mind and its openness to cultural influence and variation provides the basis for an ever-increasing representational flexibility due to external prosthetic means and symbolic technologies which then allow for culturally derived changes in the architecture of the brain." (Malafouris 2015, 355).

Cognitive artefacts may be seen as such prosthetic devices which act back on their human makers and users (see Malafouris 2013, 154). Indeed, the ways in which humans and things interact with each other, act *on* each other, is fundamental to archaeological concepts of agency (for example, Dobres and Robb 2005, Gosden 2005), although the degree and nature of this is open to question (for example, Ingold 2011, 89ff; 2013, 91ff; Barrett 2014).

However, it is not necessary to subscribe to the extended mind or the parity principle in order to pursue the agency of digital things. An alternative approach to the extended mind is one in which human cognition is seen as being scaffolded or supported by external devices, without those devices necessarily demonstrating cognition themselves. Such cognitive artefacts may operate in different ways and using different functions such that they complement human cognition – in effect they extend what the human mind can do, rather than replicate it. Sutton defines this as the *complementarity principle* in which:

> "… external states and processes need not mimic or replicate the formats, dynamics, or functions of inner states and processes. Rather, different components of the overall (enduring or temporary) system can play quite different roles and have different properties while coupling in collective and complementary contributions to flexible thinking and acting." (Sutton 2010, 194).

Menary identifies these complementary relations as *cognitive integration*, where:

> "… the coordination of bodily processes of the organism with salient features of the environment, often created or maintained by the organism, allows it to perform cognitive functions that it otherwise would be unable to; or it allows it to perform functions in a way that is distinctively different and is an improvement on how the organism performs those functions via neural processes alone." (Menary 2010, 231).

This introduces an essentially asymmetric relationship between human agent and thing rather than the broadly symmetric interaction implicit in the parity principle. In some respects, this might appear to be akin to the distinction between 'primary agency' and 'secondary agency' (for example, Gell 1998, 21) in which, unlike humans, things do not have agency in themselves but have agency given or ascribed to them. However, the increasing assignment of intelligence in digital devices which enables them to act independent of human agents could suggest that some digital cognitive artefacts possess primary agency as they autonomously act on others – both human and non-human/inanimate things. Arguably this agency is still in some senses secondary in that it is ultimately provided via the human programmer even if this is subsequently subsumed within a neural network generated by the thing itself, for example.

This is not the place to develop the discussion of thing agency further (for example, see the debate between Lindstrøm (2015), Olsen and Witmore (2015), and Sørensen (2016)); however, the least controversial position to adopt here is to propose that for the most part the agency of digital cognitive artefacts employed by archaeologists complements rather than duplicates through extending and supporting archaeological cognition. They do this, for example, through providing the capability of seeing beneath the ground or characterising the chemical constituents of objects, neither of which are specifically human abilities. So there is considerable scope for considering the nature of the relationship between ourselves as archaeologists and our cognitive artefacts – how do we interact and in what ways is archaeological cognition extended or complemented by these artefacts?

4. Cognitive coupling

Heersmink (2012, 2015), following the complementarity principle, defines what he calls the dimensions of integration between embodied agents (humans) and cognitive artefacts which can be employed in examining these relationships. Heersmink argues that these should be seen as a multidimensional phenomenon with none prioritised above another. In no particular order, therefore, Heersmink defines these dimensions as:

1. *Information flow* between agent and artefact, including one-way flow (from artefact to agent, where we simply look at the artefact to extract the information we require), two-way flow (typically where we store information on the artefact and subsequently retrieve it); reciprocal flow (a two-way flow which is incremental, additive, and cyclical, so there is a

continuous information exchange); and system flow (where there are multiple agents and multiple artefacts cooperating in the exchange) (Heersmink 2012, 49-50; 2015, 583-6).

2. *Reliability of access*, in the sense of the extent to which the artefact is required and can be relied upon. In part, this will be dependent upon the nature and properties of the artefact – for instance, battery-operated artefacts may be less reliable in that, unlike analogue artefacts, they may run out of power or suffer from ingress of water or dirt. Portability will also be relevant here – the ability of a cognitive artefact to be easily carried enhances its accessibility, whereas large non-portable instruments will be tied to a laboratory and hence less accessible (Heersmink 2012, 51; 2015, 586-7).
3. *Durability* operates in terms both of the artefact itself (its robusticity and material quality) and its purpose – for instance, a total station needs to be durable because we engage and re-engage with it (couple and decouple) over an extended period of time rather than for a one-off event (Heersmink 2012, 51; 2015, 587).
4. *Trust* – we tend to trust the devices we employ (why would we use them otherwise?) but what is this trust based upon? Typically, trust may be linked to familiarity – our trust grows as we use and come increasingly to rely on the artefact and understand the results it gives us, but trust may also be second-hand, through the fact that others use and rely on it (Heersmink 2012, 51-2; 2015, 587-8). Trust may also be linked to the openness of the hardware or software – closed systems rely on their utility, quality of output, and the reputation of the manufacturer as a means of engendering trust and conversely some find difficulty in trusting something which comes for free.
5. *Procedural transparency* concerns the degree of effort and conscious attention for the embodied agent to deploy a cognitive artefact – something that is simple and instinctive to use is highly transparent, but many of the devices archaeologists use require training over time and hence are less transparent (Heersmink 2012, 52; 2015, 588-9).
6. *Informational (or representational) transparency* relates to the ease or otherwise with which the human agent can interpret and understand the information represented by the artefact (Heersmink 2012, 52; 2015, 589-90). So, for example, a total station plotting three-dimensional data points directly to an onscreen map could be seen as having quite a high degree of transparency, whereas a proton magnetometer which requires the data to be downloaded and processed in a separate software package would have low transparency (and indeed the interpretation of the resulting plots is often not self-evident). Similarly, the graphical output of an XRF device is superficially transparent but requires expertise to interpret.
7. *Individualisation* considers the level of adjustment or customisation available to the agent. At one extreme, this may tailor the device to the individual agent such that it becomes difficult for another to use it, or to adapt it for another task. On the other hand, a device may be easy to pick up, use and understand with little scope or need for improved efficiency or effectiveness, and hence it is not especially individualised. Furthermore, agent and artefact may both be adapted together in what Heersmink calls entrenchment, where the cognitive artefact is individualised according to the user's needs, and in turn the user's behaviour and cognition are adapted by the device in a manner reminiscent of the McLuhanite "We shape our tools and thereafter our tools shape us" (Culkin 1968, 60). (Heersmink 2012, 52-3; 2015, 590-1).
8. *Transformation* is the extent to which the cognitive artefact affects the representational and cognitive aspects of the human agent. This for example is the theme behind Nicholas Carr's controversial book, *The Shallows* (2010), in which he argued that the Internet changes the way we read, think and remember. On a more basic level, however, we may need to acquire physical skills in order to use a device and in this way we adapt and transform to it, whether learning to use a keyboard efficiently or setting up a laser scanner. In the case of digital artefacts this transformation may be reversed – the device may be transformed by our

intervention, either by adjusting it programmatically, or by dynamically updating the information it works upon, for example, and adaptive learning systems are becoming increasingly commonplace (Heersmink 2012, 53-4; 2015, 591-2).

Hersmink recognises that these dimensions overlap and interact; for example:

> "If an artifact is not easily and reliably accessible, then it is hard to establish a durable relation to it. Further, reliability and durability often result in individualization. The more often a certain cognitive artifact is used, the more likely it is that it will be individualized and perhaps in some cases even entrenched." (Heersmink 2015, 594).

However, he sees these dimensions as providing a toolbox for investigating the degree and nature of the integration between agent and artefact (Heersmink 2012, 55). In effect, therefore, we can use these dimensions as the framework for constructing a cognitive biography of a digital thing (after de León 2003).

5. Cognition and the survey instrument

For example, consider the basic digital total station equipped with a data logger but without dGPS, a graphical interface, or reflectorless capability:

1. *Information flow* is *reciprocal* – we have to set the instrument up correctly over a fixed point and provide it with locational information and the height of the target in order to make the instrument operational. The instrument records horizontal distance and angle, but it is dependent on us to select the location of interest, aim appropriately at the target and trigger the reading. It is also dependent on the staff holder positioning the target correctly over the object of interest, and on both human team members correctly recording any changes in target height. The instrument reports the three-dimensional coordinates back to the user and the process repeats iteratively in the conduct of the survey.
2. *Access* is reliable in the sense that total stations are well-established pieces of equipment. The fact that they are battery-operated might make them seem less reliable, but the days of instruments losing their settings when the battery is changed have gone, and a pair of batteries will typically last a full day's surveying. Total stations are fairly resistant to rain and dirt since they derive from applications in the construction industry for instance but there are limits as evidenced in the appearance of screen or scope condensation and grit in the adjustment or focusing screws, for example. They are also reasonably portable, although carriage over long distance and rough ground generally benefits from the acquisition of a special backpack to replace the standard box.
3. A total station is quite *durable* in normal use, although it responds badly to mistreatment. Students, for example, have it drummed into them to always carry the instrument in its protective box and not to move it whilst attached to its tripod legs. A survey will typically take place over hours if not days, so the durability of the relationship is long, although since an instrument might also be set up beside an excavation trench and referred to periodically, the durability of the relationship may be repeated but not permanent.
4. *Trust* in a total station is generally high, although this is (or should be) reliant on regular calibration checks and servicing. Errors will more often be caused by incorrect use, and surveyors become accustomed to performing mental checks that the readings returned by the instrument 'make sense'.
5. The level of *procedural transparency* is dependent on experience and may take time to develop. What the instrument is actually doing beneath the surface is not transparent, especially to a novice. However, although training is required in the use of a total station, this experience can generally be applied to instruments from other manufacturers since the basic essentials are the same even if the location of buttons etc. are different. While an instrument can be used by rote, understanding of the principles behind the recording

procedures is valuable in ensuring that errors do not occur, or are recognised and can be corrected. Furthermore, understanding of the range of tools provided by the software beyond the straightforward capture of three-dimensional coordinates can enhance the setup of site grids etc. but this requires a greater knowledge of surveying practice.

6. *Informational transparency* is not particularly high, since although the coordinates generated are easily understood, keeping track of where readings have been taken is down to the skill of the surveyors. In addition, evaluating the results will generally require the data to be downloaded onto a computer and some subsequent processing undertaken for visualisation purposes. Transparency is significantly enhanced if output onto a graphical screen is built into the instrument.
7. Scope for *individualisation* is limited. There are few customisation options available beyond adjusting one or two default settings so a total station can generally be used by anyone with the appropriate knowledge. The extent to which surveyor and instrument are entrenched is debatable: for instance, one might claim that the ability to contemplate large-scale close-interval three-dimensional surveys was made possible by the increased availability of total stations; on the other hand, the level of intervention by the instrument is less significant than the processing and visualisation software in this sense.
8. To a degree, the application of total stations has been *transformative*. Anyone with experience of capturing three-dimensional coordinates using tapes and a dumpy level will know the difference the introduction of a total station makes, for example. However, it again seems more likely that the visualisation tools used subsequently are more transformative than the data capture device itself.

Overall, therefore, a total station presents a mixed picture in terms of these cognitive dimensions. It ranks reasonably high in terms of access, durability and trust, and, after training, on procedural transparency. It scores low in terms of informational transparency and individualisation, and it is difficult to assess transformative capacity although this is also likely to be relatively low. However, the reciprocal information flow would indicate a relatively close integration between agent and artefact. Indeed, the instrument is entirely dependent on the human agents for its operation, supplying in return a faster and more efficient way of measuring distances, vertical and horizontal angles and calculating three-dimensional coordinates for selected locations. Pre-digital devices required the human surveyor to read and manually record the parameters and subsequently undertake the calculations, so in this respect the digital device complements (in the sense that the human agent could otherwise perform the measurements and calculations themselves) and extends (in that the measurements and calculations are performed faster and easier than using the manual method). Human intervention and negotiation is nevertheless required, although the level and content of communication between the two surveyors is less than required for a plane table survey, for instance, and is largely replaced with the introduction of reflectorless devices, robotic total stations, and ultimately laser scanners. As survey instrumentation becomes digital and increasingly automated, so the level of human engagement changes: the cognitive load is transferred to the digital device while the survey strategy and (for now) the physical assembly and setup of the instrumentation remains on the human side of the relationship. The complexity of the task is increasingly taken over by the cognitive artefact. Correspondingly, the remoteness of the human agent from the details of the process increases – for example, time spent discussing the specifics of individual features and ensuring their accurate representation within the data is reduced considerably as the cognitive load moves from the human to the digital agent.

6. The limits of thing knowledge

A similar exercise could be conducted for any cognitive artefacts that are used by archaeologists, and clearly each will differ in terms of their balance across these dimensions. Baird (2004) has previously undertaken multiple historiographical studies of scientific instruments ranging from Faraday's electric motor to the self-calibrating spectrometer and the cyclotron, and on the basis of which he has argued that each instrument embodies what he calls ‘thing knowledge’. This manifests itself in different ways, but essentially an instrument is seen to encapsulate knowledge and theory about the world independent of its users who are distanced from the design and creation of the artefact. Baird argues that scientific instruments should be seen as a kind of objective knowledge in that, for instance, their actions provide measurements that are not directly influenced by human judgement (for example, Baird 2004, 120). Of course, while the process of measurement may be objective, its value and effectiveness relies on appropriate use and application which often remains dependent on the human component. In this respect, subjective and objective knowledge may interact with each other in arriving at an output, and consequently the outcome of the application of a cognitive artefact is perfectly capable of being misleading since it functions within an imperfect environment. We can see this in the sense that a measurement performed by a total station will be ‘correct’ within its own parameters but nevertheless ‘wrong’ because it was improperly set up or targeted in the first place. Their independence from their users is therefore open to challenge since cognitive artefacts will by definition have users who give them meaning; without users they have no purpose (for example, see Collins 2010). Similarly, their embedded knowledge is not strictly independent of their human originators, although this is becoming less true of devices employing neural networks and other means of deep-learning. In short, the human element in the creation and construction of knowledge remains fundamental, but today it is ever more scaffolded upon the knowledge and know-how embedded in cognitive artefacts. Furthermore, this ‘thing knowledge’ is increasingly compounded and reliant upon the knowledge of other ‘things’. This is nowhere more apparent than in the case of the computers we use as archaeology moves progressively more to the digital and as the claims for computer cognition become increasingly insistent.

7. Computers as cognitive artefacts

Indeed, we might anticipate computers and their software scoring the highest across the board in terms of these cognitive dimensions since they are highly malleable and flexible. Unlike a total station, for example, which although digital can only perform within certain limited survey-related parameters, the computer is capable of taking on different roles or guises, frequently simultaneously. For instance, as I write this, my computer is running the word processor that is being used to compose this text and at the same time it is also functioning as a radio playing in the background, my email program has just informed me a new message has arrived, and any number of devices from anti-virus software to hardware components are periodically checking online for updates without my intervention. Furthermore, the operating system that actually makes my computer work is invisibly managing a host of different processes: from what happens when I press a key to what appears on the screen; from low level file management that ensures I can retrieve what I create to the communication protocols used to access the printer which produces my final copy. Everything we do with our digital devices is underpinned by software driven by innumerable algorithms which are frequently characterised as invisible, black boxes. Striphas (2015), for example, has argued that our reliance on algorithms constitutes what he calls an ‘algorithmic culture’, while Bogost (2015) goes further and suggests that we live not so much in an algorithmic culture as a ‘computational theocracy’ with the invisibility of algorithms giving them a transcendental, almost divine character. In the process, algorithms can become mythologised:

> “On the one hand, they have been depicted as powerful entities that rule, sort, govern, shape, or otherwise control our lives. On the other hand, their alleged obscurity and inscrutability make it difficult to understand what exactly is at stake.” (Ziewitz 2016, 3).

Ziewitz points to the way that algorithms are seen as powerful and consequential actors, imbued with agency and impact; however, as black boxes they are difficult to understand and, in a recursive way, this tends to be read as another sign of their influence and power (2016, 5-6). These algorithms drive the collection, storage, and manipulation of archaeological data – from the capture of our data using digital instruments with knowledge embedded within their hidden algorithms to the operationalisation of data within computer systems, to the retrieval and processing of those data. In the process, different human agents take decisions in relation to the design of algorithms, the implementation of algorithms, and the input to algorithms, and take actions arising from the output of algorithms. Our application of a computer is therefore effectively a collaborative venture, whether we realise it or not, combining human and algorithmic agency in a complex web of interrelationships which remain largely unseen and seemingly impenetrable. Our use of these tools is ultimately mediated by the actions and decisions of those who designed and created them – and may well have done so without our mode of use specifically in mind. Berry characterises this environment as one in which:

> "code/software lies as a mediator between ourselves and our corporeal experiences, disconnecting the physical world from a direct coupling with our physicality, whilst managing a looser softwarised transmission system." (Berry 2012, 381)

and argues that this requires careful description and critical attention not least because of the way that software hides its depths behind its interfaces (2012, 382). He introduces the notion of *compactants* – computational actants (2012, 391) – which operate silently and surreptitiously or, where the human agent is aware, offer perceived value and benefits that lead to them disappearing into the background again.

One logical response to this situation is to do nothing – to abrogate responsibility to the ubiquity of the machine in an essentially powerless, subservient relationship to the digital tools we use on a daily basis (Huggett 2004, 2012a). It might reasonably be argued that we do not need to know the model of processing at work, and indeed, using a well-designed black box system can seem to be effortless and unequivocally valuable. On the other hand, the inadequacy of many algorithmic models relative to the intuitive, action-situated nature of human intention means that the content of the black boxes should be highly visible (Hamilton *et al.* 2014). If that is the case, and faced with such complexity, how do we sensibly move forward? What do we as end-users need to know about in our use of these tools? What should we understand? What can we reasonably understand? How much do we need to know about the ordering principles and bases of the tools we use (Hamilton *et al.* 2014)? Even assuming that the algorithms underlying the software we use were accessible – a key aspect of the argument in favour of the archaeological use of open-source software (Marwick 2016; Ducke 2015, for instance) – the knowledge required to understand and disentangle the code is considerable, and trust in the correct implementation of routines and processes by others remains ultimately necessary. In fact, it is becoming the case that even programmers themselves do not always understand what the software system is actually doing: for instance, Google's DeepMind software extends its own neural network by teaching itself, creating a computationally incomprehensible black box. Demis Hassabis, one of its founders, believes that in future:

> "The system could process much larger volumes of data and surface the structural insight to the human expert in a way that is much more efficient—or maybe not possible for the human expert … The system could even suggest a way forward that might point the human expert to a breakthrough." (Metz 2016).

8. Unpacking cognitive compactants

Black boxing is a process which makes the productions of actors and artefacts opaque (Latour 1999, 183), and the degree of invisibility of that process can be seen as a measure of its success. It is only when one of our digital devices stops working or behaves unexpectedly that we become aware of it as constituting one or more black boxes, especially when we realise we are unable to fix it or make it work again. Such success – and hence invisibility – is perhaps why it is all too easy to overlook the need to understand the structures, operation, and outcomes of a technology by opening the box. Consequently, difficult or not, arriving at a critical appreciation of our computational cognitive artefacts is key to understanding their effects on our own cognition.

Four distinct approaches may be characterised to this end: a critical reading of the program code/algorithm itself, a critical appreciation of the software package, a critical engagement with the creative process of the design of software, algorithms, and other structuring aspects of the computational environment, and a critical understanding of the use of the hardware/software applied within an archaeological context.

8.1. (De)Coding compactants

It is generally appreciated that programming languages affect the way that program designers and developers think. In 1975 Dijkstra defined this as one of the truths of computing science:

> "The tools we use have a profound (and devious!) influence on our thinking habits, and, therefore, on our thinking abilities." (Dijkstra 1982, 129).

Similarly:

> "Software developers as a species tend to be convinced that programming languages have a grip on the mind strong enough to change the way you approach problems—even to change which problems you think to solve." (Somers 2015, 81).

As a result, Berry argues for a need to understand program code and the systems so constructed since:

> "A close reading of code can … draw attention to the way in which code may encode particular values and norms … or drive particular political policies or practices." (2011, 9).

Furthermore, Berry demonstrates the ways in which code can be designed to disguise or mislead, whether deliberately or inadvertently (Berry 2011, 75ff). Consequently, access to code is key to the concept of reproducible research (for example, Marwick 2016). As Ducke argues, "the ability to track data through complex processing chains is key to successful collaborative research" (2015, 93) and the only way to understand the mathematical models and formal reasoning behind a computer-based archaeological study is through examining the source code (2015, 99).

This implies a degree of digital literacy which is rare amongst archaeologists. However, that aside, the transparency that ought to be implied by reading the source code is not straightforward. Understanding the breakdown of computational tasks and the formalisation of practices and methods underpinning the computational analysis through making the code and algorithms explicit will frequently be highly challenging. Access to the code itself may not be feasible (hence Ducke's argument for open source software in archaeology), but if available, it may not be easily interpretable – either through obfuscation or the sheer complexity of the code, especially problematic if that code is itself created by the software rather than the human agent. For example:

> "… certain techniques imported from the computer sciences may never be understood in the same way we understand statistical concepts like variance or regression because there no longer is a 'manual' equivalent of the automated approach." (Rieder and Röhle 2012, 76).

So for commercial reasons and/or lack of expertise, the actions of code may score very low in terms of Heersmink's dimensions (2012, 2015) of access, procedural and informational transparency, although high in transformative terms and, perhaps paradoxically, very high in terms of trust.

8.2. Software compactants

If close reading of the program code is unrealistic for the majority, raising the level of introspection from the algorithms themselves to the software they reside in is perhaps more feasible. Approaching a software package as a cognitive artefact in its own right offers the prospect of achieving a closer appreciation of the ways in which the software subtly holds us at arm's length amidst an illusion of transparency. This is not to deny the levels of digital abstraction which are employed to shield us from the complexities of the software, or the levels of literacy required to understand its operation, but it recognises the limitations of unpicking our relationship with the digital while providing a means of better understanding the ways in which archaeological cognition is affected by these tools.

Such a focus needs to go beyond the application of the software to include its interfaces, operation and use; we need to understand:

> "… what *functions* it offers to create, share, reuse, mix, create, manage, share and communicate content, *the interfaces* used to present these functions, and *assumptions and models about a user, his/her needs, and society* encoded in these functions and their interface design." (Manovich 2013, 29 – emphasis in original).

Few software tools used by archaeologists over the years have received the same level of attention as Geographical Information Systems (GIS). However, relatively little of that attention has been paid to acquiring an understanding of how they may have affected archaeological practice since, for example, Lock and Harris (2000, xvii) pointed to the spatial determinism imposed by the requirements of points, lines, polygons, and pixels, and the constraints imposed on complex data through the requirement to partition them into layers. More recently in a critique of the implications of GIS within archaeology, Hacıgüzeller asked:

> "… how did our GIS representations and practices come into being across time and place and how did/can they become part of the complex process of creating past worlds in the present?" (2012, 257).

This epistemological critique is undertaken at a broadly conceptual level of GIS, focussing on theory and representation rather than more specifically the functionality, interfaces, and assumptions embedded within the GIS software. An alternative approach which looked more closely at functions and underlying assumptions (Huggett 2012a, 210-212) sought to examine GIS through the application of McLuhan's four 'laws' of media (McLuhan 1977, 175): how GIS amplified function, obsolesced practice, retrieved or re-emphasised theory and practice, and, to some extent, what GIS reversed into or become. This was followed by a consideration of the oppositions between the laws which drew out the often paradoxical or contradictory effects of using GIS (Huggett 2012a, 212). Again, this examination does not really address either the basic characteristics identified by Manovich or the cognitive dimensions defined by Heersmink. Instead, these approaches sit alongside Heersmink's dimensions, although the idea of inherent oppositions within McLuhan's laws might suggest that there could be value in explicitly examining oppositions *between* the dimensions of cognitive artefacts as a means of pursuing the overlaps and interactions between them that Heersmink (2015, 594) refers to.

Such studies are very much in the minority, however, and the few historiographies of archaeological computing that there are (most recently Djindjian 2015, Moscati 2015) tend to focus at a high level on people, organisations, and techniques rather than software applications. What is missing are critical historiographies of the tools themselves, including software which might be perceived as mundane – for instance, examining the relationships between word processing and archaeological report writing (analogous to Kirschenbaum 2016), or spreadsheets and post-excavation analysis. However, it should not be assumed that this is a simple proposition – focussing on a software package all too easily becomes a case of accounting for and justifying its use in a specific context. The cognitive approach helps avoid this by emphasising the range of implicit, explicit, and tacit assumptions and beliefs wrapped within the social, political, and technical environment (Huggett 2012a, 207).

8.3. Creating compactants

A drawback with considering code and/or software as cognitive compactants is that they represent the end of a design and development process – the code is constructed and shaped to create the software which is subsequently selected and applied within an analysis. A more complete approach to understanding a cognitive artefact in this situation would be to engage with the initial design and development process as a means of appreciating the series of debates, decisions and compromises surrounding its production in advance of its application. The search for understanding digital development is also found in digital anthropology (for example, see contributions to Horst and Miller 2012) and digital ethnography (for example, Hine 2015). For instance, Kelty (2008) used historical and ethnographical methods to examine the free software movement, including the development of UNIX/Linux and allied software (and see also Karanović 2012 for example). Such approaches are not a feature of archaeological work, although recent examples of the beginnings of such an approach include a description of the circumstances surrounding Oxford Archaeology's contribution to the development of the open source GIS software, gvSIG, (Ducke 2015, 104-107) and a discussion of the early conception of the Archaeological Recording Kit (ARK) including the background and theoretical leanings of the development team (Dufton 2016).

These aside, one reason for this lack of discussion within archaeology is that archaeologists rarely create their own tools – as noted above, most tools are adopted and repurposed from elsewhere. However, if the creation process behind the artefact is not accessible, an act of creation may yet apply since most computer tools will require data to be structured, prepared, and collected in a specific way prior to implementation. For example, a computer database places requirements on the organisation of the data held within it, as does a spreadsheet, and these affect both what is recorded and how it is subsequently accessed. This may have considerable implications for the cognitive processes supported by such tools (for example, Huggett 2015, 21-24). By way of illustration, ontologies structure and underpin web tools for the access and retrieval of archaeological data and an ethnographic approach to understanding their creation has been proposed (Huggett 2012b, 546-548). This would follow the development of an ontology through its initial conceptualisation, development and implementation, tracking the processes and participants with a view to understanding the decisions, policies and strategies that are otherwise embedded within the ontology and the consequent implications for its application and use (Huggett 2012b, 547). So even if the creative processes behind the construction and manufacture of the cognitive artefact are not available for inspection, ancillary acts of creation prior to its implementation and use in a specific context may well be.

8.4. Using compactants

Examining the underlying code and algorithms, understanding the functions, interfaces, and assumptions underlying the software, and probing the structuring principles and creative processes behind the artefact leads inexorably to the fourth component in understanding the digital cognitive artefact: its subsequent context of use. Again, this lends itself to an ethnographic approach, examining how the digital artefact is used, constraints associated with its application, results achieved, and so on.

As before, this is not a common feature of archaeological work, although it is the case that the introduction of new techniques does encourage the presentation of workflows which go some way to beginning to address this. For example, De Reu *et al.* (2013) describe a method for three-dimensional recording of archaeological features using digital photogrammetry, while Roosevelt *et al.* (2015) describe the complete digital workflow of a digital site recording system incorporating 3D spatial recording of spatial contexts. Generally, however, such studies tend to be cast in terms of improving efficiency, streamlining procedures, simplifying processes and increasing consistency – hence superficially rational and essentially utopian in outlook. Although Roosevelt *et al.*, for example, argue that the results are positive because it leaves more time for archaeological engagement with the physical material (2015, 342), the suspicion remains that such ideals may be notional rather than actual, especially in a commercial environment. The drawback of a workflow approach is that, by definition, it outlines a working procedure, one that is successful according to the criteria applied and one in which negative aspects – if mentioned – are challenges that have been overcome. Similarly, the pages of the annual Computer Applications in Archaeology conference proceedings are filled with accounts of applications and case studies of their use, but examples of failure are rare not least because the incentives for authors and publishers to report successes are naturally greater. Adopting an ethnographic approach which employs Heersmink's cognitive dimensions could go a considerable way in coming to a more nuanced understanding of the context of use of a compactant.

9. Contemplating cognitive things

The investigation of digital cognitive artefacts can be visualised as a form of cognitive archaeology in the sense of extracting cognition from a digital artefact layer by layer (after Edmondson and Beale 2008, 129): from its conception, through its implementation in algorithmic form as code, its incorporation behind interfaces in software, and ultimately its use in an archaeological context. These layers represent an accretion of practices, decisions, and compromises by a host of different agents, by no means all archaeological, many of whom will be unaware of each other. Already a complex challenge, this situation is heightened by the fact that these digital artefacts were not created with a view to making their cognitive processes recoverable in the first place (Edmondson and Beale 2008, 129).

Although considering the computer as a digital cognitive artefact highlights these challenges, they are equally true of other digital artefacts – even a device as comparatively straightforward as a total station or a digital camera relies for its operation on algorithms which for the most part we cannot access. It has to be remembered, however, that it is not necessary for a user to recover the cognition within an artefact to make successful use of it (Edmondson and Beale 2008, 129). Nevertheless, the ubiquity of digital devices within archaeology makes it important to study and understand their integration into archaeological practice, and the different dimensions of cognitive artefacts help to characterise the agent/artefact relationship and the extent to which archaeological cognition is supported and complemented. However, as we find ourselves using digital devices which transcend our own abilities and which in some instances create the phenomena which we are seeking to record, when devices operate in ways we do not fully understand, and when designers seek to make devices more 'user-friendly' and in the process disguise their mode of operation, it becomes all the more important to investigate the role of cognitive artefacts within archaeology and the relationships and dependencies that exist within the digital ecosystem we are creating.

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