Archeologia e Calcolatori
30, 2019, 13-20

ARCHAEOLOGY AND COMPUTERS: A LONG STORY IN THE MAKING OF MODERN ARCHAEOLOGY

1. The origins of computational archaeology

To celebrate the 30th anniversary of the Journal «Archeologia e Calcolatori», and following the examples of the 1st, 10th and 20th issues (Djindjian 1990, 1999, 2009), an assessment of the recent evolution of computer applications in archaeology is here presented.

The very beginnings of quantitative and computational archaeology date back to the Fifties, as now illustrated in the Virtual Museum of Archaeological Computing, an international web portal dedicated to the history of this discipline (http://archaeologicalcomputing.lincei.it/). In brief, three major references are worth picking out: the pioneering role of Jean-Claude Gardin (Djindjian, Moscati 2016), with the foundation in 1957 of the CADA laboratory (*Centre d'Analyse Documentaire pour l'Archéologie*), and two conferences organized by the Wenner-Gren Foundation in Burg Wartenstein castle in 1959 (Heizer, Cook 1960) and 1962 (Hymes 1965).

Since those pioneering times, archaeology has passed through several major stages:

– Science in archaeology (1955-1975): semiotics, palaeoenvironment, archaeometry;
– Multidimensional data analysis (1975-1995): the development of quantitative archaeology;
– Geographic Information Systems (1995-2010): from site archaeology to landscape archaeology;
– Multi-agent systems (from 1995): past societies seen as a complex system;
– 3D archaeology (from 2010): realizing the utopia of a total field archaeology.

The emergence of a new discipline calls for a new name. In our case, many such have been put forward, following the evolution of Computer Sciences (see Moscati, in this volume). 'Archaeological computing' seems to be the more popular expression, while 'Computational archaeology' would be the more correct one, in keeping with the practice in other Sciences. The word 'Digital archaeology' or 'Digital Antiquity' has a still more recent use, probably due to the success of the digitization revolution of technology, corresponding to the pattern of its usage in 'Digital Heritage', and to the actual development of Virtual Reality (VR) and 3D applications.

Several scientific journals and international conferences have been devoted to computational archaeology, which is evidence of its current status as a scientific discipline (for an exhaustive excursus, see Djindjian 2015). In the new Millennium, the rapid development of Virtual Archaeology, for which Cultural

Heritage is a market application more worthy of funding than archaeology, created the opportunity for more focused conferences, such as the VAST Euroconference (Virtual Reality, Archaeology and Cultural Heritage), and the biannual conference Virtual Retrospect (for the first editions, see Niccolucci 2002 and Vergnieux, Delevoie 2004, respectively). VR is a very dynamic field of research and its application to Cultural Heritage is quite spectacular. For example, in 2009, no less than five conferences have been reported with a focus on archaeology: Malta, Trento, Paestum, Bordeaux, and Seville (the European capital of VR in archaeology), and more than a dozen about VR in general. Since 2010, all these events have come together in the 'Digital Heritage' conferences held at Marseille (2013), Granada (2015) and San Francisco (2018). The very fast development of a 3D archaeology, not only in Cultural Heritage, can be seen as a revolution also in field archaeology and therefore applicable to all the data processing after the step of recording excavations and surveys.

2. What position in the academic world?

Vertical organization is viewed as the best option in the academic world, particularly in the university environment, where creating a chair means that the discipline truly exists. Today, though, it is more frequent to have a research laboratory to handle computational archaeology (for general purposes or dedicated to GIS, VR, data banks, etc.) than specific university chairs. A typical example is the laboratory at Sydney University, directed by I. Johnson, or the Archaeology Data Service at York University, directed by J. Richards. Probably the first in the field was the Technical and Computer Methods Department at the Rheinisches Landesmuseum, Bonn, directed by Irwin Scollar.

An organization operating on a transverse plane is the most efficient way to develop computational archaeology – by sharing projects and courses, applicable to all the archaeological specialties, themselves often structured according to geographical and chronological patternings. It requires some kind of matrix-based constitution, which theoretically would be well adapted to the integration of various other disciplines from different sciences (physics, geology, zoology, botanic, computing, mathematics, etc.). Unfortunately, this kind of organization, which is so efficient in the very dynamic and competitive world of industries and services, proved unsuccessful in many conservative countries like France, Italy, Spain and others. The consequence is a very arduous and slow progress in the discipline, hindered by institutional and sociological resistance, probably in the same way as has affected archaeometry.

Just as with all new scientific disciplines, the pioneers of computational archaeology have been scientists of rich and varied backgrounds, including the hard sciences and also human/social sciences. Many of them produced numerous students who have become the second and the third generation of specialists in this discipline, for example John Wilcock from the School of

Computing of Staffordshire Polytechnic or myself in the Paris 1 University. It is possible to identify several different profiles that tend to repeat:

– Computer scientists or engineers who are considering archaeology as a serious hobby. Some of them are very reputable specialists in their official field and their archaeological researches accordingly have a very high scientific level (for example Jim Doran).
– Computer scientists who are interested in archaeology as a field of application. This approach offers an opportunity to receive grants from the European community or from a national institution and to use archaeology as a nice 'shop window' for their advanced computerized projects. Today, applications in Digital Heritage often seem to fall into this category.
– Archaeologists who are involved in quantitative and computational techniques for their research (statistics, mathematical modeling, GIS, 3D, etc.), or who are using modern archaeological computerized methods, or who are involved in the production of formalized (and then computerized) archaeological knowledge. They represent the future of computational archaeology.

Specialists of computational archaeology occupy very different positions, sometimes depending on the sociology of archaeology as it exists in their different countries. They may be:

– Archaeologists using modern techniques, methods and formalization procedures. In that case, they may play major academic roles in archaeology, both in university or research institutes. However, they are firstly specialists of an archaeological period and area, as it was the case of F.R. Hodson (European protohistory), C. Renfrew (European Neolithic), G. Cowgill (Mesoamerica), J.D. Clark (Neolithic), O. Buchsenschutz (Iron Age), F. Djindjian (European Upper Palaeolithic) and many others.
– Technicians working for archaeologists who are not able to do it themselves. A typical case is the French CNRS, which employs specialists in computational archaeology as ITA (engineer/technician/administrative people) and not as researchers. It means that CNRS commissions (section 31 and 32) refuse to recruit PHD students with a profile in computational archaeology as researchers. As a consequence, students choose not to try for a PHD on computational archaeology, because they know they will not find a job as a researcher either in CNRS or in the university (this was also the case in the Seventies for archaeometry). Such an attitude acts as a constraint on the development of modern methods and techniques in French archaeology.
– Experts working in a specialized laboratory in an archaeological institute. Unlike a laboratory for archaeometry, the creation today of a laboratory of computational archaeology does not call for a large investment. In France, such laboratories existed in the Sixties and Seventies (CADA, LISH) in Human and Social Sciences, but they have been finally shut down. The context of the

recent creation of a VR laboratory in Bordeaux by R. Vergnieux is symptomatic of these difficulties, as it succeeded only after a long struggle with the Ausonius archaeological institute. To be successful, such a laboratory has to work with archaeologists in communal projects and in a multidisciplinary way. If such cooperation is not feasible, then they end up working alone and independently. It was the case for the department of use-wear analysis in Saint-Petersburg created by Y. Semenov in the Fifties, and it is the case today with the laboratories of paleogenetics.
– Specialized suppliers that archaeologists have to pay for. Examples of private laboratories are rare. Their existence depends on the approach taken by governments in applying liberal politics in rescue archaeology. Startup companies have been created for 3D processing in archaeology and Cultural Heritage.

A major factor in all this is the scientific background experienced by students in archaeology. Archaeology is increasingly taught in Human Sciences faculties, although it uses extensively methods and techniques from physics, mathematics, computing, and earth sciences. Such a situation could lead to a decline in the scientific level of the new generation of archaeologists. Whatever the case, computational archaeologists will be often considered as statisticians or computer scientists. Glory (a priest studying palaeolithic art) once said of Leroi-Gourhan that he was a technician in mechanics, because he used punched cards (and knitting needles) to study the European palaeolithic art!

3. What methods and techniques for computational archaeology?

Computational archaeology has used almost all the techniques and tools of applied mathematics and computer science. The primary importance of separating the techniques (which are always improving and often updated) from the methods or best practices (which are only optimized) has been repeatedly emphasized. The techniques are the area of competence of computer scientists or statisticians, while the methods are the area of competence of archaeologists. For example, it is fundamental to distinguish the sample dating (competence of the radiocarbon laboratory) from the site dating (competence of the archaeologists).

The following list of themes, which are chapters of a textbook of archaeology (Djindjian 2011), reveals the major role of computational archaeology in the archaeological workflow: Archaeological BPM (Business Process Management), Prospection, Excavations, Stratigraphy, Sampling for rescue archaeology, Typology, Stylistic analysis, Seriation, Culture historical identification, Intra-site spatial analysis, Urban spatial analysis, Archaeology of the construction, Raw material and manufacturing characterization, Landscape analysis, Image processing, Environmental studies, Exchange systems, Virtual Archaeology, Demography, Food resource management system, Transition models, Collapse models, Economic models, Network analysis, Complex system reconstitution, Culture Resource Management (CRM), Epigraphy, etc.

4. Towards a generalized cognitive framework?

The books published by J.D. Clarke in 1968 (*Analytical Archaeology*) or by J.-Cl. Gardin in 1979 (*Archaeological Constructs*) have revealed that the formalization of an archaeological construct is also the aim of computational archaeology, exactly as in Artificial Intelligence. Looking at the last fifty years, it is possible to distinguish two different approaches in the archaeological constructs:

– The constructs are embedded, explicitly or not, in an ideology, as paradigms or theories (in the Anglo-Saxon meaning). They may be considered as operating an *a priori* reduction of the variety of possibilities (in French *la réduction du champ des possibles*): evolutionism, Marxism, neo-Marxism, functionalism, cultural ecology, gender theory, substantivism, Marrism, Kossinnism, behavioral archaeology, evolutionary archaeology, symbolist archaeology, hermeneutic post-modern approaches, with the risk of opening the Pandora's box of neo-Lysenkoism. Such a reduction may be useful only if it is used not like a dogma (even if this is generally the definition of an ideology), but like a motor of inference to explore the explanations which may be deduced (with the obligation to having an external validation process).
– The constructs must be formalized, helped by a cognitive framework (in other words, an epistemology), which is nothing else but a theory of knowledge. It was the case for the *analyse logiciste* of J.-Cl. Gardin or the Pierce logic-based approach of the *triplet systémique* by F. Djindjian (1980). In such a context, the historical opposition between the processual archaeology (New Archaeology) of the Sixties and the post-processual archaeology (or symbolist archaeology or post-modern archaeology) of the late Eighties – which is also a classical opposition between structuralism and hermeneutics – appears to be very archaic in comparison with the progress of cognitive sciences.

The specialists in computational archaeology are surely the best positioned to be the promoters of a renewal of the theoretical framework of archaeology. An example of such a contribution (among others) is the question of the complementarities between the data-oriented approach and the process-oriented approach. In Computer Science, there is a classic completion between the data-oriented approach (data bases and data storage), the computation approach (algorithmic), and the process-oriented approach (real time).

The archaeology of the 19th and 20th centuries has been mainly a 'data-oriented archaeology', following the Montelius typology and the corpus programs, renewed in the Seventies by the data retrieval systems (archaeological data banks), and more recently by the Internet, materializing the 'back office' of archaeology. The process-oriented approach concerns firstly the organization of the archaeological activity (APM or Archaeological Process Management), secondly the study of the reliability and the representativeness of the archaeological record (taphonomy), and thirdly the systemic reconstitution of past societies (Djindjian 2014), proposing in fact a post-Montelius revolution in archaeology, something actually in progress:

– Manufacturing process (replacing typologies);
– Identity process, transition process, adaptation process and resilience studies (replacing cultural and historical archaeology);
– Territory process management (from site archaeology to landscape archaeology);
– Processes of governance, social attitudes and beliefs (towards a systemic reconstitution of past societies).

5. How to implement a global, generic, scalable, compatible and sustainable approach in computational archaeology

The fundamental trend of the progress of Science has always been to search and find a generic and common framework that applies equally to apparently different sciences. Justly famous is the case of the equations of J. Maxwell, merging Magnetism and Electricity in the same rules. Are there, then, several archaeologies with their own paradigms and methods, or is there a single one, having the same core of epistemology, methods and techniques? Of course, the second case is the correct one. Formalizing a common generic Archaeological Information System (AIS) should be a proof of its success. The way forward is today well known:

– Urbanization of the business processes of archaeology: cultural heritage management, documentation, surveys, excavations, laboratory works, restoration, archiving, conservation, dissemination;
– Acquisition of archaeological information: norms, ontology, scanning, recording;
– AIS: standardization and genericity; customization; functional, application and software architecture;
– Commercial software solutions: DBMS, GIS, CAD, 3D, VR, statistics (R), modeling, Internet, etc.

The first step is to identify the Archaeological Process Management which answers precisely to all the processes of the archaeological research and management, sets up an organization of archaeological professionalization, urbanizes the AIS and makes more rational and interchangeable the design of the AIS application and software architecture.

The second step is to define the AIS 'objects':

– Artifacts and sets of artifacts (spatial structures/building/urban system);
– Archaeological sampling (core, trench, zone, square, unit, layer, level, etc.);
– Geo-archaeological sampling (sedimentology, pedology, palynology, etc.);
– Measures (geophysical, geochemical, dating, etc.);
– Drawings (stratigraphy, planigraphy, architectural mapping, photogrammetry, photo cover, etc.);
– Documents (text, bibliography, photography, film, Internet site, etc.);
– Administrative documents (excavation authorization, royalties, property document, etc.).

The third step is to define the main categories of AIS 'information', complying with archaeological standards and norms:

– Intrinsic Information (II): a description of the object;
– Extrinsic Information (IE): the archaeological context of the objet;
– Reference Information (IR): documentation;
– Management Information (IA);
– Naming Information (thesaurus, ontology).

The fourth step consists in building the AIS, including the definition of the processes, the objects, the information (II, IE, IR, IA), the functional architecture and the application architecture, implementing the software and hardware in a generic architecture.

6. A program for the "21st Century Archaeology"

Computational archaeology has the ability, and indeed the responsibility, to continue to be a driving engine for the constructing of a modern archaeology, one able to introduce more precision into our knowledge and so to reconstruct more trustworthy interpretations of past systems. The following list is an example of such a program:

– Start over on projects of thesaurus and ontology in all the archaeological fields;
– Create multimedia databases to save millions of archaeological slides and drawings;
– Compose international archaeological standards;
– Pursue and implement the 3D revolution;
– Consider the existing processes and systems, and then renew all the archaeological approaches;
– Integrate simulations, governance processes, social organization, societal attitudes, believes, etc. into the multi-agent system;
– Work with a real multidisciplinary approach, being inspired by new computerized techniques and their integration;
– Achieve high level of academic training for new generations of archaeologists and provide specialized laboratories in research institutes and chairs of 'Archaeological Methods and Theory'.

The 21st-century archaeologist is no longer a soil scraper: he incorporates other disciplines, like History, Epigraphy, Geography, Anthropology, Ethnology, Economy, Agronomy, Physics, Chemistry, Mathematics, Computers, etc. He is faced with the compelling task to reconstruct the complex system of a past society from partial, biased and often insignificant archaeological and epigraphic data. He has also a role in his own society: to comprehend the past for understanding the present and anticipating the future. He is the only scientist to have the knowledge of the depth of the time. In such a challenging environment, computational archaeology may play a major role only if specialists choose to work under a single umbrella, with a single scientific journal (like «Archeologia e Calcolatori») and interacting under the aegis of a single series of conferences, one well accepted and open to all.

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ABSTRACT

The growing success, for more than fifty years, of the scientific contribution of computer applications and quantitative methods in archaeology may be now reviewed and analyzed from different technological and sociological points of view. This examination allows us to appreciate the material importance of such contributions and how the community of specialists in computational archaeology should play a major role in the future of 21st-century archaeology.