Archeologia e Calcolatori
Supplemento 6, 2014, 85-112

ANALYTICAL ARCHAEOLOGY AND ARTIFICIAL ADAPTIVE SYSTEMS LABORATORY (LAA&AAS)

1. Theoretical and analytical background of the LAA&AAS

The background from which the first fundamental experiments were conducted by McCulloch and Pitts (1943) and soon after those by Hebb (1949) was a neurobiological study conducted in order to interpret the neurons as logical devices. The scientific theory behind this research is known under the name of Connectionism (Rosenblatt 1958, 1962; Minsky, Papert 1968; Feldman, Ballard 1982; Grossberg 1982; Pylyshyn 1984). According to this cognitive theory, the brain is not the result of a system of rules and symbols but is composed of simple elements: neurons. Since it is the wide range of connections between neurons to express coherence properties and cognitive abilities, the connectionist approach represents a reaction to the so-called Behaviourism (Minsky 1986; McClelland, Rumelhart 1986; Ackley 1987; Fodor 1987; Grossberg 1987; Fodor, Pylyshyn 1988; Anderson, Rosenfeld 1988; Smolensky 1989). The behaviourist theory rejected the study of Artificial Intelligence based on dynamic and connective relations between neurons, and intended to interpret the logic of their operation according to a mechanical Input-Output stream (Herz, Krogh, Palmer 1991; de Callataÿ 1992).

1.1 *LAA&AAS theoretical background*

Artificial Adaptive Systems can be defined as a set of formalised structures of Natural Computation (Beckerman 1997; Mira *et al.* 2009) that describe, simulate and reproduce natural and cultural processes and/or turn them into dynamic and complex artificial processes. Indeed, recent advances in neurobiological study of the Artitificial Intelligence suggest that stochastic variation and controlled selection in programmed mechanisms can guide neural development and learning. Natural Computing is a general term referring to the computing occurring in nature and to the computing inspired by nature systems (Elman, Rumelhart 1989; Feldman, Ballard 1989; Churchland 1989; Clark 1993; McCulloch, Pitts 1993; Arbib 1995; Marcus 2001; Clark, Eliasmith 2002; Rogers, McClelland 2004; McClelland *et al.* 2010). When complex natural phenomena are observed as computational processes, our comprehension of these phenomena and of the essence of computation are enhanced. In this way we may acquire valuable insights into both natural sciences and computer science. On the other hand, the metaphorical use of concepts, principles and mechanisms underlying natural systems is characteristic of the man-designed computing inspired by nature.

This type of computing includes evolutionary algorithms, neural networks, molecular computing and quantum computing. On the methodological level, it is one of the most advanced set of techniques dealing with the problems of classification and data-mining (Ackley 1987; Bishop 1995; Tastle 2013). On the morphological level, Artificial Adaptive Systems can be further subdivided into Evolutionary Systems and Learning Systems. The so-called Artificial Neural Networks (ANNs) are organised as Learning Systems and constitute a family of algorithms inspired by the functioning of the human brain (Minsky 1954; Zadeh 1965; Hopfield 1982; McClelland, Rumelhart 1986; Grossberg 1988; Kosko 1992; Gallant 1993; Bishop 1995; Zadeh *et al.* 1996; Szczpaniak 1999; Baxter 2006; Nunes de Castro 2007).

Given this premise, the Sapienza LAA&AAS is mainly interested in experimenting/testing the theories, methods, models and algorithms of Artificial Sciences applied to the analysis of archaeological, anthropological, geographical and linguistic complex systems. From the historical point of view, therefore, these research activities are inspired directly by the mainly European methodological traditions of Computational Archaeology, Cognitive Archaeology and Analytical Archaeology (Clarke 1968; Gardin 1970, 1980, 1987, 2002, 2003; Doran, Hodson 1975; Renfrew, Cooke 1979; Renfrew 1981; Gallay 1989; Baxter 1995; McGlade, Van der Leeuw 1997; Camiz, Rova 2001; Camiz 2004; Beeckman, Baden 2005; Barceló 2007; Baxter, Cool 2010).

1.2 *LAA&AAS analytical background*

As noted, the epistemic architecture of the LAA&AAS is also interested in the strong interaction between the computing environment of Geographic Information Systems and analytical tools of non-linear dynamical systems, thus embracing some of the modern analytical tendencies that have been recently developed in the American and English Settlement Archaeology (Kvamme 1990; Allen 1999; Zubrow 2003; Kohler, van der Leeuw 2007). Therefore, although LAA&AAS is built on the line indicated in 1968 by Clarke's Analytical and Computational Archaeology (Clarke 1968, 1972, 1973, 1994), its morphology does also recognise the contemporary and now widespread and diversified cognitive approaches (Renfrew, Zubrow 1994; Djindjian 2002).

However, if the LAA&AAS deals with applied neuroscience in order to outline ancient, universal shapes and/or cognitive behavioural, contextual ones (Renfrew 2008; Malafouris, Renfrew 2008, 2010a-b), it does also develop the tools and computational models of Artificial Intelligence as a base method for the analysis of communicative, spatial and linguistic complex phenomena. The rapprochement between physic-mathematical sciences and the cognitive sciences does still present proud and sometimes intimidating obstacles, but it is also fascinating and able to open the archaeological research up to new perspectives (Ramazzotti 2010a, 199-203).

Indeed, we must always keep in mind that some of the most important scientific discoveries of the modern age were precisely achieved by adapting new technologies and meta-disciplinary testing to specific reserch contexts. For example, the study of the archaeological and geophysical environment integrated with vector maps, Geographic Information Systems, geophysical maps and automatic classification of geomagnetic anomalies led to the extraordinary discovery of the Temple of the Rock (2400-2350 BC) at Ebla - Tell Mardikh, in northern Syria (Ramazzotti 2008, 2009a, 2010b).

The linguistic and philological sphere, starting from glossematic and generative semiotics, textual criticism and the application of phylogenetic trees to texts encoded as systems allowed to reinterpret the criteria of semantic distinction in literary construction (Canettieri *et al.* 2005, 2006; Canettieri 2012); and in image analysis the study of the aesthetic and cognitive level, made through autopoietic classification systems and logical formalisation of the processes, allowed to recognise latent cultural factors in the syntax of ancient cylinder seals iconography (Di Ludovico, Ramazzotti 2008; Di Ludovico 2011) as well as ideographic codes in the construction of only apparently decorative geometric forms (Di Ludovico, Ramazzotti 2011).

Finally, the simulation of settlement processes through Artificial Neural Networks not only allowed to overcome the rigid context of the Systems Theory, offering an unexpected opportunity to expand the so-called multifactorial analysis to the earliest Mesopotamian urbanisations (Ramazzotti 1997, 1999a, 2000, 2002, 2009b), but also to design and program instruments for bottom-up predictive spatial analysis that attempt to overcome the descriptiveness of satellite photography (Ramazzotti 2013a, 2013b).

All those applications constitute a stream of approaches which depend on and follow the international success in design Artificial Adaptive Systems for key problems of contemporary researches.

2. The LAA&AAS experimental procedures

All the following experimental elaborations in the LAA&AAS have been realised in two steps: the first step was the Artificial Adaptive System Analysis, mainly applied by testing different typologies of Artificial Neural Networks on different alfanumeric databases and the second step has been the representation of the results through different graphs and tables.

Each analysis has been conducted in autonomous way but always respecting the same experimental protocol discussed in the LAA&AAS and centred on the contextual evaluation of each complex configuration results. In fact, although the ANNs are formalised mathematical structures that present highly various forms (cfr. BUSCEMA *infra*), their common characteristics can be summarised as follows:

A) The minimum elements of every Artificial Neural Network arranged in layers are nodes, elements that can be processed (Processing Elements), and connections (Weights); B) Each node of an ANN has a definable Input layer as a form of external environment interface; an Output layer and one or more interlayers, such as Hidden layers, which constitute the real Black Box network, the logical place for the learning activities of the network; C) A transformation function through which, starting from the Input signal, a global Output is generated.

2.1 *Artificial Neural Networks morphology*

Each connection is characterised by the strength through which node pairs can either excite or inhibit node pairs: positive values indicate excitatory connections, negative ones show inhibitory connections; in addition, the connections between the nodes may change over time. This dynamics triggers a learning process in the ANN: for each model the transformations of the connections are generated by an equation, conventionally called the Learning Equation.

The overall dynamics of an ANN is connected to time: in order to allow their connections to change, the processed data need to be acting symmetrically and repeatedly on the topological structure. The overall dynamics of an ANN is linked not only to the local interaction of its nodes. The final evolutionary state of an ANN must thus emerge spontaneously from the interaction of all its syntactic components (nodes arranged in layers).

Communications between nodes in each ANN tend to occur in parallel; such parallelism can be synchronous or asynchronous, but each model expresses and may emphasise it according to modalities and different shapes. Each ANN must have the following components of architecture:

A) type and number of nodes and their property;
B) type and number of connections and their location;
C) type of signal flow strategies;
D) type of learning strategies.

The nodes of each ANN can be at least of 3 types, depending on the position they occupy within the network: Input Nodes: nodes that receive (even) signals of the external environment of ANN; Output Nodes: nodes whose sign acts (even) on the external environment of ANN; Hidden Nodes: nodes that receive only signals from other nodes of ANN and send their signal to other nodes of ANN.

The number of Input nodes depends on the way we want the ANN to learn the environment/context: in this sense they can be labelled. When the environment of an ANN consists of data that are to be processed, each Input node becomes a variable type of the data. The number of Output nodes depends on the way we want the ANN to act on the environment, so the Output can be defined as network and the effector will represent the expected variables (or the results of the processing). The number of Hidden nodes depends on the complexity of the function that we want to map between Input nodes and Output nodes. Each ANN nodes can be grouped into classes of nodes that share the same characteristics (properties).

2.2 *Artificial Neural Networks topology*

Usually these classes are called layers and they involve different types of ANN: 1) monolayer ANN: when all nodes of ANN have the same characteristics; 2) multilayer ANN: when ANN nodes are grouped into functional classes, share the same signal transfer functions, but receive only signals from nodes of other layers and only send new layers; 3) spatially relevant ANN (or ANN without layers): when each node is specific to the position it occupies in ANN, for example, when the closest nodes communicate more intensely than the more distant ones. Each connection can be of five types:

1) Mono-directional;
2) Bi-directional;
3) Symmetric;
4) Anti-symmetric;
5) Reflexive.

The number of connections is proportional to the storage capacity of an ANN. The location of the connections is appropriate for the pre-processing of the methodological problem that ANN will face, but is not required. ANN in which not all connections between nodes or between layers are enabled is referred to as ANN with dedicated connections; otherwise we talk about ANN maximum gradient. In every ANN connections can be of three types:

1) Adaptive: when the learning equation changes;
2) Fixed: when the connections keep fixed values for the whole learning time;
3) Changed: when the transformation is structured in a deterministic way.

In each ANN the signal may proceed in a linear way (from Input to Output) or in complex ways. In this case, there are two main strategies: 1) ANN Feed forward: when the signal processing from the Input to the Output of ANN traverses all nodes once (Mangan *et al.* 2003); 2) ANN with Feedback: when the signal goes with specific Feedback, determined *a priori*, or tied to the occurrence of certain conditions. The ANNs with Feedback are also called ANN Recurrent (Mandic, Chambers 2001). More biologically plausible, although mathematically more complex to discuss, they are often used for temporal signal processing.

2.3 *Artificial Neural Networks learning*

Each ANN can learn over time the characteristics of the environment in which it is situated (or the data that are presented) in two ways that are interdependent with each other:

1) by reconstructing approximation to the probability density function of the data it receives from the environment, compared with pre-sorted constraints;
2) by reconstructing approximation parameters for solving the equation of connection between Input and Output data, compared with pre-sorted constraints.

The first method is known, in Artificial Intelligence, as Vector Quantification; the latter is defined as a method of Descending Gradient (Gradient Descent). The method of Vector Quantisation consists of Input variables in the Output consisting of hyper-spheres radius defined (Gersho, Gray 1992). The Gradient Descent method consists of Input variables in the Output consisting of hyperplanes (Snyman 2005).

The difference between these two methods becomes evident in the case of Feed-forward ANNs with at least one layer of Hidden units. Using the Vector Quantification, the Hidden units code locally relevant sections of the Input vector; when learning is complete, each Hidden unit is a prototype that represents one or more values of the Input vector, defined and exclusive. Using the Descending Gradient too the Hidden adapters encode the relevant sections of the Input vector, but at the end of each unit, Hidden learning will tend to represent part of the Input in a more fuzzy and not exclusive way (Bishop 1995; Baxter 2006; McClelland *et al.* 2010).

The LAA&AAS Experimental Protocols have been first applied to some problems posed by Analytical Archaeology, Spatial Analysis, and Computational Linguistics, immediately showing significant results. The simulations have, in fact, concerned very large databases that were treated using different and specific Neural Analysis Techniques: Linear Correlation, the so-called Prior Probability Neural Network and Auto-Contractive Map, the latter designed at Semeion Research Centre (Buscema, Grossi 2007, 2008; Buscema, Terzi 2007; Buscema 2008; Buscema *et al.* 2008a, 2008b).

2.4 *Artificial Neural Networks testing*

In the case of Linear Correlation, a square matrix was created for each database to represent the correlations of the registered and formalised entities in linear pairs. In the case of the Prior Probability, connections were traced to indicate the *a priori* probability of the co-occurrence of each pair of entities.

The neural network Auto-CM, at last, which is based on an algorithm that can highlight non-linear relationships between all entities understood as dynamic clusters, created a matrix containing information that is different from the information obtained through the other two types of simulation.

After these three processing, for each database the best results obtained have been selected and configured to be visualised in a graph of MST type (Minimum Spanning Tree) or in a graph whose vertices are the minimisation of energy present within a data structure composed of Atomic elements and standards that define mutual relations (Kruskal 1956; Graham 1985; Gabow *et al.* 1986; Fredman, Willard 1990). In other words, these branching graphs display the most significant associations between the entities/variables of each database – those specific relationships between entities and/or groups of entities that represent the best records of each dataset.

The analytical procedure observed had, therefore, to verify the different connective (associative) capacity of the models used, and to extrapolate those neural learning graphs with a greater complexity, not only in order to confirm the already known information, but also in order to identify new and otherwise not recognisable present or latent non-linear correlations.

3. A synthetic overview of the LAA&AAS applicative fields

The elaborations have been produced by means of a software programmed in the LAA&AAS, written in C++ language, using both the best-known Artificial Neural Networks as tools for the computing of the Minimum Spanning Tree algorithm, which is able to process the results in a format suitable for the spatial visualisation of graphs with open-source software GEPHI v. 0.8.1. The results of AAS in each applicative field can now be discussed on the epistemological and historical-cultural level.

3.1 *Technology and aesthetic of the images*

The integrated applications of GIS and AAS can also be considered a sector of the Spatial Analysis whose goal is the extrapolation of semantic constraints between the spatial-temporal distribution of archaeological features and the technological character of the objects distributed. In the LAA&AAS, technology and aesthetic of the Near Eastern clay figurines have been investigated through this integrate approach which implies the neural analysis of the semantic clusters obtained by applying geomatic technologies on the spatially referenced clay objects and/or subjects.

In particular, the GIS and AAS analysis on some clay figurines dated to Early and Middle Bronze Age and recently discovered in Tell Mardikh (Syria) displayed that during the Early Syrian period, the spatial concentration of clay figurines in the Royal Palace G of Ebla demonstrates some kind of affinity between the world of miniature clay and the sacred Kingship. On the contrary, the spatial distribution of the clay figurines during the Old Syrian Period is extensive, but the strong concentration of fragments close to the Ishtar public cult area (Monument P3 and Temple P2) seems to indicate a radical transformation of the roles played by this clay world (Figs. 1-2). It would no longer impersonate a *Mimesis* of the physical and metaphysical sacred Kingship, but rather a reproduction of the whole society (Ramazzotti 2012a).

Starting from the recognition of this semantic discontinuity, different typologies of ANNs have been tested on the 100 clay figurines, topographically referenced, in order to explore, select and classify which technological variables could be related to the spatial distribution, and to suppose from which cognitive principle the semantic transformation could be moved. The preliminary Neural Analysis displayed in the tree-graph defines a mapping of connections between variables that reconstructs the image elaboration techniques and provides material and cognitive information about the technological and psychological processes that might have occurred (Figs. 3-4). In fact, the ramifications of the graph classify three different kinds of information:

1) Since the vertices indicate one of the parts that make up the image, the largest Summit, i.e. the Summit with the highest Betweenness Centrality (Betweenness Centrality is a normalised value that represents a measure of centrality of the Summit in a generic network that is equivalent to the number of shortest paths), identifies the predominant variable in the production of these images – the incision as the most important technique for the figurative construction of the image.
2) Different classes, represented by different colours (here translated into grayscale), seem to indicate different quality groups of variables that gather to build the technological and cognitive complexity of each individual figurine; therefore, we can get a geometric hypersurface by encoding the systemic cognitive and technological complexity of each one of the 100 records processed.
3) The thickness of the lines that connect the nodes, or vertex weighted connections, indicates the measurement of the contiguity between the different variables that describe each figurine of the database (in terms of degrees of probabilistic transition), and is directly proportional to the values of the connections; these branched connections, in other words, indicate the quality and intensity of technological and cognitive relations between all the variables that have been chosen to describe every single figurine.

Thanks to this methodology not only we could then confirm that these productions of the so-called material culture were also a conscious human imitation of the sacred and royal images of power, but a very accurate reconstruction of the cognitive mechanisms underlying the specific connections between figures typologies, technologies of the images productions, and their spatial distribution will be possible in future.

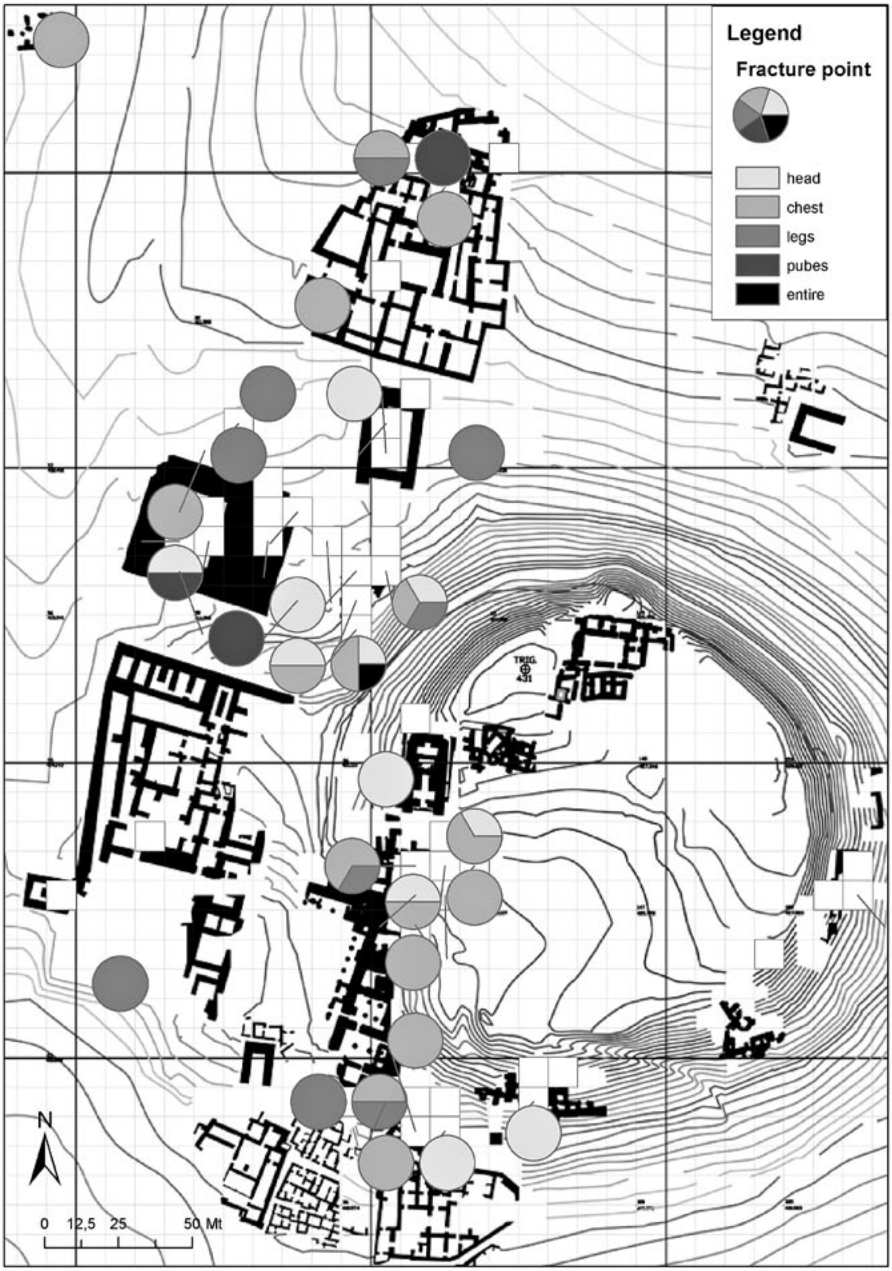


Fig. 1 – Spatial distribution of 100 clay figurines main breakages (heads; chests; legs; pubes; complete) from Ebla dated to the Early Bronze period (Ramazzotti 2014).

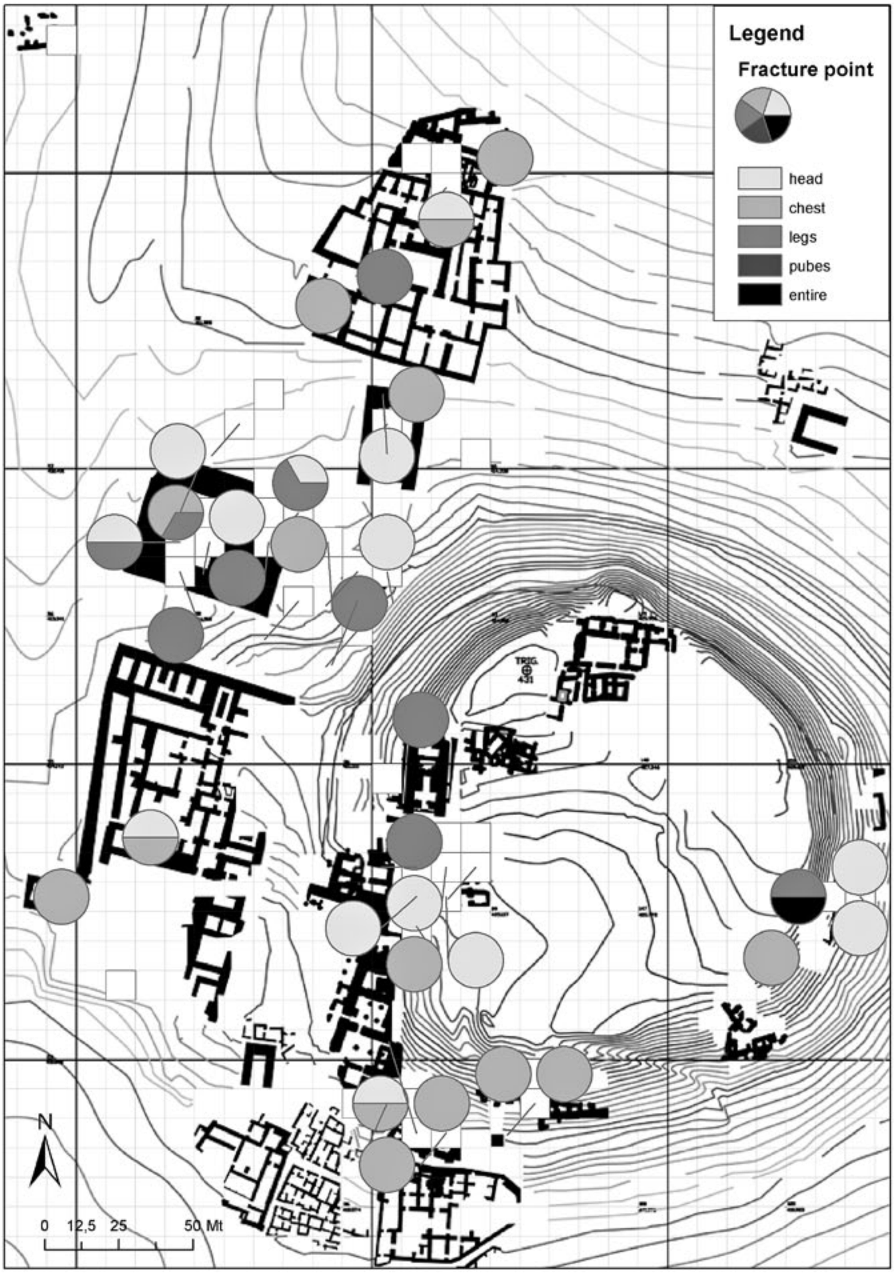
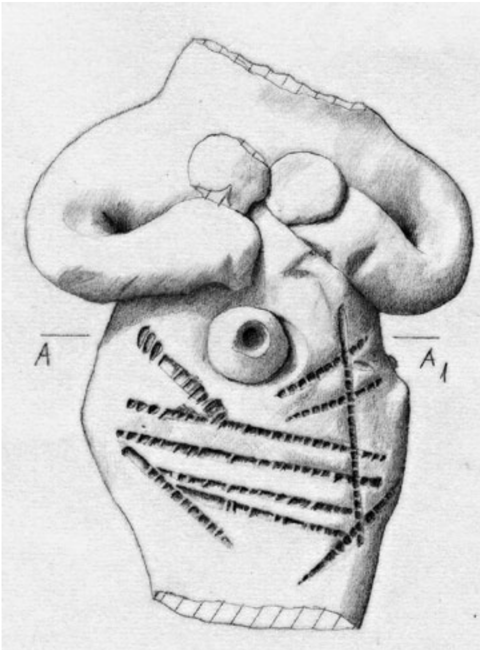


Fig. 2 – Spatial distribution of 100 clay figurines main breakages (heads; chests; legs; pubes; complete) in the Middle Bronze period (Ramazzotti 2014).



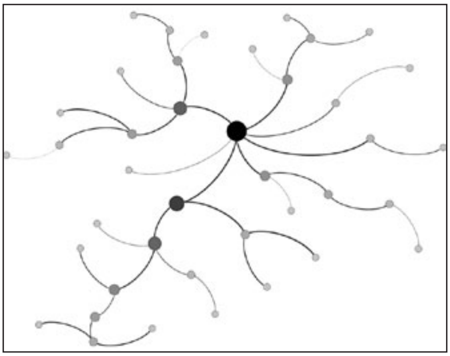


Fig. 3 – Drawing 1:1 scale of a clay figurine from Ebla in Idlib Museum (TM92P618) and dated to the Early Second Millennium BC.

Fig. 4 – The MST tree-graph defines a mapping of connections between variables that reconstructs the image construction techniques and provides material and cognitive information about the technological and psychological processes that might have occurred in Early Syrian and Old Syrian clay figurines (Ramazzotti 2013c).

Indeed, the preliminary results of the ANNs applications outline a spatial-symbolic *chaîne opératoire* of these clay objects revealing their ideographic and composite character (which can be recognised also in Early Dynastic and Early Syrian miniature composite statue tradition) and unexpected relationship between this ideographic character and its spatial distribution (Ramazzotti 2013c; 2014).

3.2 *Digital iconography and computational iconology*

The so-called Natural Computing can also be considered a sector of Cybernetics whose goal is the reproduction of some segments of the cognitive process. On the methodological level, it is one of the most advanced set of techniques dealing with the problems of seriation and data classification. Since it reproduces and expands some functions of the cognitive and perceptive behaviour, it can also be reasonably applied to the iconographic interpretation of ancient documents.

In the LAA&AAS, cylinder seals, a class of artefacts originating from pre-classical Mesopotamia, have been investigated through different computational methods – corresponding to even more numerous points of view, but a selected *corpus* of late Third and beginning Second Millennium BC glyptic scenes has been explored in depth through a perspective implying the analytical examination of their compositional patterns (Fig. 5). The ANNs allowed to locate some interactions that could be reasonably proposed as means for an interpretation of both the development of the glyptic presentation theme and

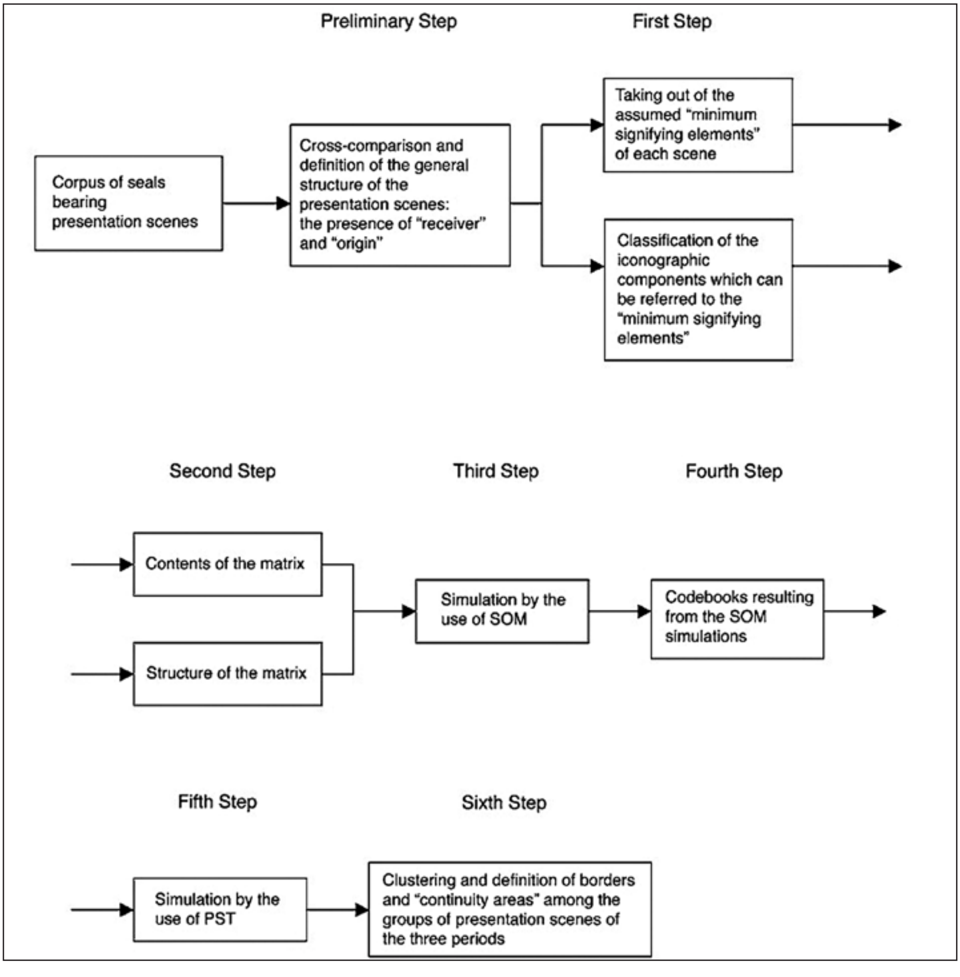


Fig. 5 – The Mesopotamian Cylinder Seals experimental process. The simulations concerned a particular Mesopotamian glyptic production dating to the Akkadian, the Post-Akkadian, and Ur III periods. After a careful formalization of the data into mathematical language, some numerical matrixes have been formed and processed using different AAS. The outline of the iconographic profile of the dataset entries led to group the Ur III presentation scenes (at the end of Third Mill. BC) into iconographic classes for which a narrative, besides a logical ground, as well as a position in the history of the logical development of the relevant theme can be postulated (Di Ludovico, Ramazzotti 2008).

the inner logical structure of single specimens (Di Ludovico, Ramazzotti 2008; Di Ludovico 2011).

The outline of the iconographic profile of the dataset entries led then to group the Ur III presentation scenes (at the end of Third Millennium BC) into iconographic classes for which a narrative, besides a logical ground, as well as a position in the history of the logical development of the relevant theme can be postulated (Fig. 5). Moreover, the analysis of a *corpus* of seals belonging to the period of Isin and Larsa carried out through the use of the Neural Network Auto-Contractive Maps, allows us to understand the complexity of the relationship of the different elements of the visual domain and its variety. The point of view here adopted is that of reading the iconography of the so-called "presentation scene" by offering an interpretation that goes beyond and transcends the concept of standardised and homogeneous production without any peculiar innovative connotations (cfr. Viaggiu *infra*).

Finally, different typologies of ANNs have already been applied to different iconological problems posed by identity recognition of the maenads and their multiple interactions with the satyrs on Athenian red-figure vases. The encouraging results of the huge amount of data have helped highlighting several interesting elements of the iconographies of maenads and satyrs. The results seem to confirm the highly interesting role of AAS methodologies as innovative tools for the organisation, visualisation and analysis of complex data in History of Art and Classic Archaeology (cfr. Wayenberg *infra*).

3.3 *Computational linguistics and dynamic philology*

For the biosemiotic linguistc theory (Gamkrelidze 2009), inspired by the so called Biosemiotic Paradigm (Uexküll 1957), an isomorphism existing between the genetic code and different semiotic systems can be traced and simulated designing natural and artificial adaptive systems (Frank 1996). If so, every kind of communications system can be studied after being transferred in a non-linear sequence of variables and can be simulated as semiotic systems to approach and to test also such isomorphism between languages and genetic codes (Ramazzotti 2010a, 88-127).

In the LAA&AAS we are testing many computational models based on AAS to explore languages as semiotic systems (Fig. 6), following many connectionist experimental approaches applied to simulate both normal and disordered word production as well as child language acquisition and symbolic grammars syntaxes (Koskenniemi 1983; Pinker, Prince 1988; Seidenberg, McClelland 1989; Faisal, Kwasny 1990; Nakamura *et al.* 1990; Pollack 1990; Elman 1991; Zipser 1991; Seidenberg 1994).

In particular, different experiments have been conducted on the ancient Mesopotamian communicative system founded on ideographic codes (Fig. 6).

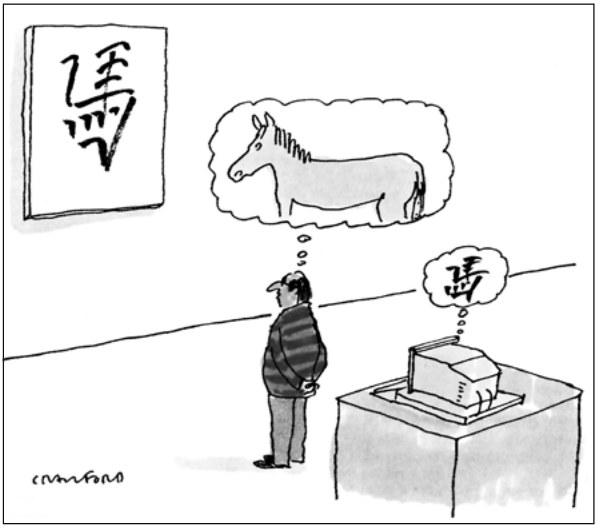


Fig. 6 – Computer programs are formal (syntactic), the human mind has mental contents (semantics) (Searle 1982).

In fact, although most scholars agree that the first ideographic writings had an administrative-economic origin, in the past a few solitary voices such as those of A. Hertz and K. Szarzyńska suggested a possible iconographic origin of the first written (Ramazzotti 2013d); and the origin of writing in the Land of Sumer has been discussed as a problem of historical epistemology dealing with «cognitive development in prehistory from the perspective of Jean Piaget's genetic epistemology, applying concepts such as the concept of sensory-motor intelligence, preoperational thought, and operational thought to the early development of human intelligence» (Damerow 1996, 1).

Since connectionist approaches have been criticised, for instance claiming that a proper linguistic method should be able to represent constituent structures and to model compositionality (Fodor, Pylyshyn 1988), in the LAA&AAS the possibility of analysing the constituent figurative structures of the first Mesopotamian ideographic writing systems has been tested. The main aim of this approach was to realise a detailed stylistic analysis of some of the pictographs engraved on the seals and this analysis identified many iconographies featuring images as related to specific ideograms signs that are present in the Sumerian cuneiform writing (Di Fede 2011).

In the next future in the LAA&AAS different typologies of AAS algorythms will be experimented in order to connect self-organised classes of the archaic figurative features of seals and *cretulae* with the first ideographic signs of the Sumerian language, and therefore to verify the suggestive theory of an iconographic origin of the first ideographic communicative systems and to detail the complex isomorphisms between images and words in Sumerian Linguistics.

Philology is a human science primarily applied to literary texts and traditionally divided into lower and higher criticism. Lower criticism tries to reconstruct the author's original text and higher criticism is the study of the authorship, style, and provenance of texts (Canettieri 2012; Canettieri *et al.* 2006). Methods borrowed from Dynamic Philology and Information Theory shows an implicit critic to the raw cladistics interpretation of the dichotomy-phenomenon (cfr. Canettieri *infra*).

In the LAA&AAS the outcome of the experiments of both text criticism and text (authorship) attribution, applied through AAS to Fernando Pessoa's texts, which represent an extreme case in the context of contemporary author's philology, were encouraging. The Pessoa archive explored through the use of ANNs, is bringing to a new light the complex and multi-layered writing system built by Pessoa, by identifying new genetic relationships among his works, useful for the construction of an overall mapping of his literary output (cfr. Celani *infra*).

Epigraphy is another human science applied to the written words and texts, but cuneiform epigraphy is a specific research field dealing with the semantic relations between ideographic codes, cuneiforms signs, texts and supports. In the LAA&AAS a sample of administrative cunieform texts from the Early Syrian state archives of Ebla were coded and processed through different models of AAS and the preliminary results of this study stress some basic issues related to the morphological and semantic structure of some Eblaite administrative records.

The first step has been oriented toward the development of a computational epigraphic methodology which could help to outline some well-grounded proposals for reconstructing the content of badly preserved clay tablets. The experimental results highlight the central role played by the physical size of the sections of each document, but at the same time they lay the foundations to rethink the typology of texts themselves and some possible sub-classifications (cfr. Di Ludovico *infra*).

3.4 *Spatial Archaeology and Human Mobility*

In the Spatial Archaeology the Human Mobility has been studied mostly through linear relationship between the settled area of the sites and the number of inhabitants. In the LAA&AAS we experimented the latest generation of AAS in order to underline a non-linear relationship between spatial distribution, morphology site, macro-economical variables and chronological sequences (Ramazzotti 1997, 1999a, 1999b, 2009b, 2013a, 2013b).

Indeed AAS are not only an ordinary complement to the spatial analysis' toolbox but they represent a new paradigm for spatial analysis and data mining. In particular Geo-SOM (Geo-Self-Organizing Map) is a tool to identify homogenous regions for which predictive analysis can be done using tools that allow the visualisation of positive and negative correlation (Viaggiu 2013). An increasingly intensified use of AAS and GIS, and the good results this method contributes to reach a more precise identification of a GIScience in general and of its research agenda in particular (Buscema *et al.* 2013; cfr. Montanari *infra*).

In the LAA&AAS this approach has been tested in order to create an artificial predictive model of the Third Millennium BC Ebla Settlement System. In particular, this methodological and applicative proposal is founded on a bottom-up predictive model of the Ebla / Chora, and it processes geographic positioning hypothesis of mausoleums of Nenaš: the most relevant and still unknown sacred place of the Ebla Hinterland, which is mentioned in the famous «Ritual of Kingship» as a step of the rite of enthronement and as a holy place of worship of the deceased kings (Fig. 7).

Specifically, the contemporary archaeological sites located on a given territory were encoded in a network of dynamic connections later tested by a series of new-generation algorithms that had already successfully been applied in epidemiology for the identification of the place of origin of some infectious diseases. The Neural Model was trained first for the recognition of the location of the Royal Tombs of Ur in the Ur and Eridu settled area, then it was experienced in the *Chora* of Ebla to generate locational hypotheses on the mausoleums' geographical position (Fig. 7a-b). This model has been built testing Minimum Spanning Tree (MST) and Topological Weighted Centroid (TWC) algorithms (Buscema *et al.* 2013) on an Ur-Eridu settlement system formalised as an Artificial Neural Network hypersurface and generated by an Auto-Contractive Map (Auto-CM).

The MST and TWC applications on an Ur-Eridu neural hypersurface has been calibrated in order to detect in the Ur-Eridu region the position of an "Event Zero", intended as the localisation of an important "Origin Area". Since we considered a strong ideological relationship between Ur and Ebla, and since we assumed a strong symbolic value of this "Origin Area", and since we experimentally observed the unexpected spatial overlapping between this "Origin Area" and the area of the Ur Royal Cemetery, we applied the same analytical methodology in order to discover another "Origin Area" in the Ebla-Chora settlement system.

If we consider this "Origin Area" an important cultural and symbolic area of the Ebla landscape (as this Origin Area was in the Ur-Eridu region), we suppose that the site isolated by the MST analysis and polygon selected by the TWC algorithm in the Ebla-Chora settlement system could reveal

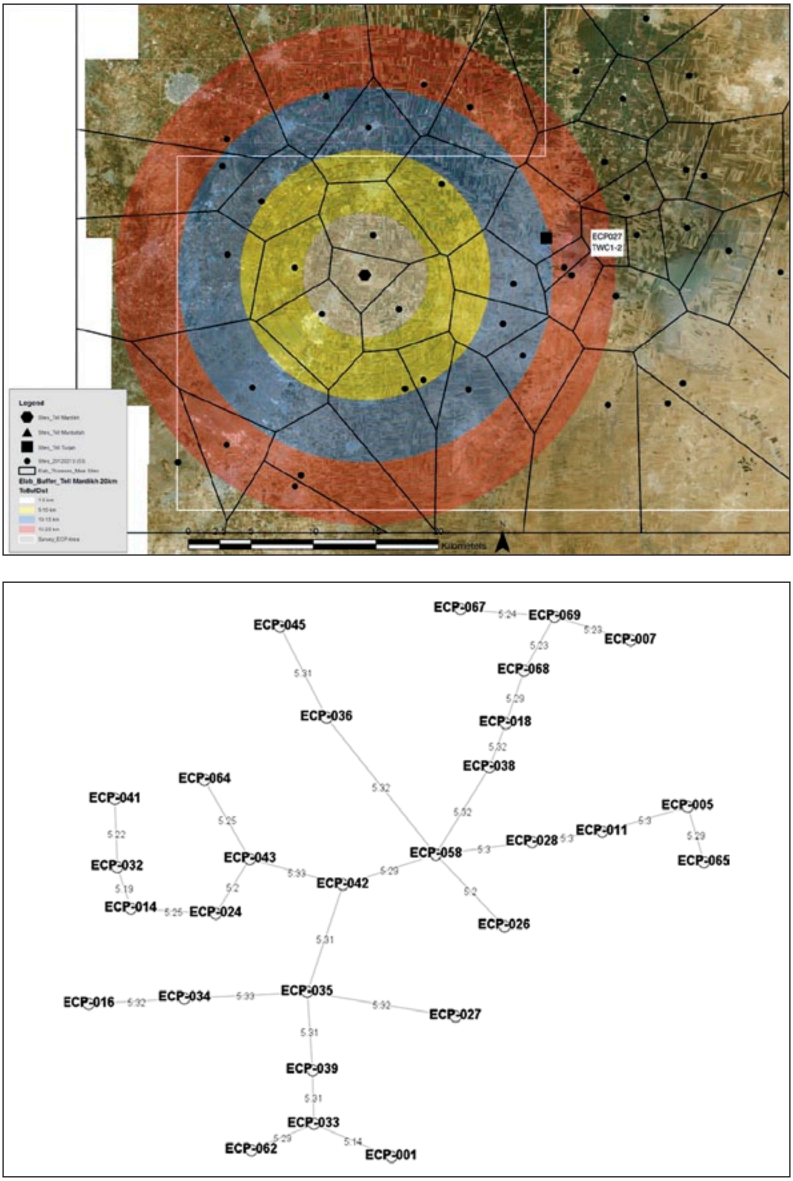


Fig. 7 – a) Thiessen Polygons map of the Ebla-Chora Survey area with the localizations of TWC 1-2 points; b) the results of MST test in the Ebla-Chora Survey area. The Ebla Chora Neural Model was trained to generate locational hypotheses on the royal mausoleums' geographical position. This model has been built testing Minimum Spanning Tree (MST) and Topological Weighted Centroid (TWC) algorithms on an Artificial Neural Network hypersurface generated by an Auto-Contractive Map (Ramazzotti 2013b).

some important "cultural and symbolic" characters, such as the well-known cultural, symbolic and religious characters of the so-called Nenaš Mausoleums, the undiscovered intermediate destination of the «Ritual of Kingship» (Ramazzotti 2013b).

3.5 *Physical Anthropology and Self-Organised classifications*

The Self-Organizing Map (SOM) is an unsupervised type of network which offers a classification of the input vectors creating a prototype of the classes and a projection of the prototypes on a n-dimensional map able to record the relative neighbourhood between the classes. The way SOM operate in reducing dimensions is by producing a map of the similarities. So SOM codebooks accomplish two functions, they reduce dimensions and they display similarities (Fig. 8).

Since the graph obtained by SOMs of a certain extent recalls a classical Multidimensional Scaling (MDS) or a Principal Component Analysis (PCA) plot, but they can handle vectors with missing components without interpolating missing data, in the Near Eastern Archaeology this autopoietic classification method has been proposed for describing non-linear high complex socio-economical systems, such as the so called Southern Mesopotamian Urbanism System (Ramazzotti 2002).

Moreover, in the LAA&AAS the SOM applications has also been proposed as an experimental biometric approach to analyse the dental morphologic relationships between archaic Homo and anatomically modern Homo sapiens (Fig. 8). The principal result indicates a close relationship between Homo erectus s.l., Middle Pleistocene specimens and the later Neanderthal groups. Furthermore, the dental models of anatomically modern Homo sapiens are particularly different compared to those of more archaic populations. Thus, SOMs can be considered a valuable tool in the field of dental morphological studies since they enable the analysis of samples at an individual level without any need to interpolate missing data or to place individuals in predetermined groups.

4. To be continued

ARCHEOSEMA (Artificial Adaptive System for the Analytical Archaeology of the Complex Phenomena) is an analytical model-procedure for theoretical and experimental researches. Applications, experiments and analyses are currently being conducted at the LAA&AAS, Department of Science of Antiquities at the Faculty of Philosophy, Letters, Humanities and Oriental Studies at La Sapienza University of Rome.

The LAA&AAS results of the project show, with evidence, that Artificial Intelligence and Artificial Adaptive Systems can be trained to detect

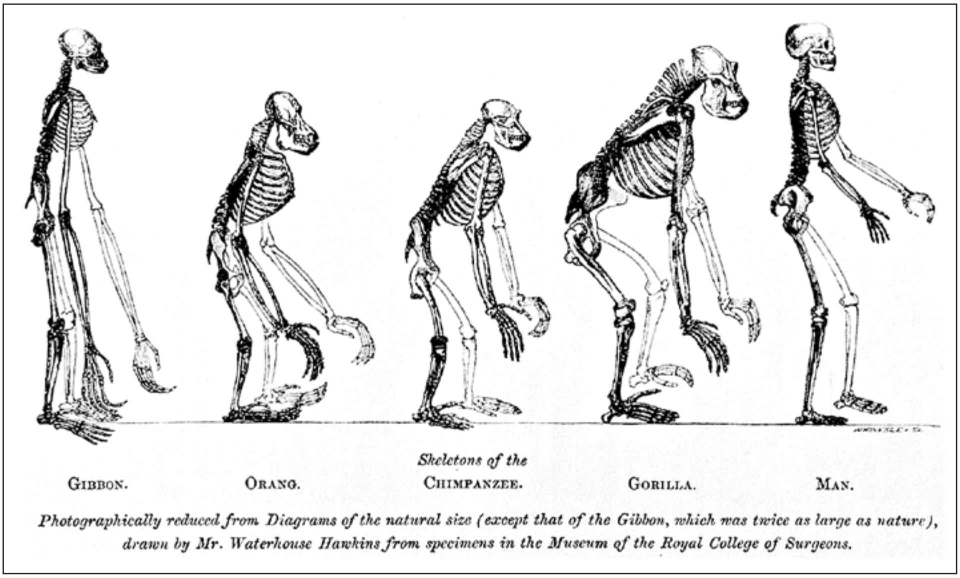


Fig. 8 – This illustration was the frontispiece of *Mans's Place in Nature* (1863). Thomas Henri Huxley applied Darwin's ideas to show that humans and apes had a common ancestor, which challenged the assumed theological thesis that humans held a unique place in the universe (HUXLEY 1863).

the fuzzy rules of a given complex data configuration, and may formalise this into a geometric graph that dynamically turns in relation to learning and inputs it receives. Specifically, the application of the Artificial Neural Network to the ARCHEOSEMA databases created different hypersurfaces which represent the same neural learning of each, distinct, complex data configurations. These hypersurfaces which encode some of the scientific problems posed by Analytical Archaeology, Spatial Analysis, and Computational Linguistics were subsequently translated into tree-graphs and in GIS maps that summarise the dominant semantic and spatial characters of each treated configurations.

A new exploration of these characters and/or constraints has already been introduced, and aims at an always better (and in *quantum* terms) definition of the object of investigation, and at the examination of how this object changes the shape analysis when emphasising, adding or subtracting some variables.

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ABSTRACT

This contribution represents a further attempt to synthesise and to introduce the research activities of the Analytical Archaeology & Artificial Adaptive Systems Laboratory (LAA&AAS) recently instituted at La Sapienza University of Rome thanks to the award of the project ARCHEOSEMA and to the institutional collaboration of the Department of Antiquities and the Department of Intercultural and European Studies and Physic Department. The main didactic and empirical activities of the Laboratory are related to the applicative simulations of Artificial Adaptive Systems to the analysis of complex natural and cultural phenomena through the lens of Analytical Archaeology. These complex phenomena are essentially understood to be the product of cognitive behaviour, in other words models and ideal-types which represent it and can be analysed on a formal logical level. This introductory exploration leads to a significant syntactic diversification of logical inferences and a progressive human attempt to trace them back to the simulation of cognitive complexity. Artificial Adaptive Systems, as Natural Computation mathematical tools which express these emulative properties, are historiographically involved in the connectionist reaction to behaviourism and therefore they effectively form the social sciences' attempts to ascribe the complexities developed by our brains to advanced, non-linear and dynamic computational models. The LAA&AAS results will be examined in a historical perspective, but it is of great importance to consider the epistemological implications of this new approach since it is moved by the idea that every kind of language can be studied after being transferred into a non-linear sequence of variables.