Cultural Heritage between Natural and Artificial Intelligence

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Abstract

The human interaction with cultural heritage is analysed from the point of view of the artificial intelligence. In this framework a cultural asset is the access point for the mental reconstruction of an era, a cultural environment and a culture. The techniques of machine learning and augmented reality are exploited to reconstruct this space-time mental environment, transforming the use of cultural heritage into a more comprehensive experience. By means of the artificial intelligence techniques the cultural heritage information can be arranged on a graph whose subgraphs correspond to different description of the same topic. Finally an effective example is discussed.

Keywords
conditional probability, artificial intelligence, forecasting, cultural heritage.

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Introduction

These pages are devoted to the comparison of the natural mental models with the models made by means of artificial intelligence for the comprehension of the cultural heritage. The reliability of the two approaches is assessed by the reliability of the comparison of their predictions with the phenomena we are dealing with, making also necessary to clarify what we mean by reality. This apparent philosophical speculation turns out to be useful for the study of the ancient archaeological finds, where the perception of the monuments leads the mind back to the reconstruction of different objects, different times and different contexts [Andrianaivo 2019].

The Conditional Probability

The analysis begins with one of the least intuitive concepts in probability theory: the conditional probability, defined by the well known formula

$$P(A \mid B) = \frac{P(A \cap B)}{P(B)}$$

that states that the probability of the event A, given the event B, is the probability of the common elements of the two events divided by the probability of the event B. If we roll a dice and we get a prime number, then the probability of getting 2 is a conditional probability. A dice has only three prime numbers, $B = \{2,3,5\}$ and the probability of getting 2 is 1/3, but the probability of getting a prime number when we get 2 is 1 because 2 is a prime number: the conditioning is not symmetric

$$P(A \mid B) \neq P(B \mid A)$$

This result is simple, but it is also cause of misunderstanding. In fact, if two events are independent then $P(A \cap B)=P(A)P(B)$ and $P(A)$ does not depend on B:
"*If it is night and a cat appears, we will certainly see it grey, while the mere fact that a cat appears grey does not necessarily mean that it is night: perhaps it is a very bright day in August, but the cat is really grey*" [Marinari 2004]:

$$P(\text{grey cat} \mid \text{it is night}) = 1, \quad P(\text{it is night} \mid \text{grey cat}) < 1$$

A further pitfall is the possible confusion of the conditioning with the cause. One event can be conditioned by another, the two events can be strongly related, but this does not mean that the one is the "cause" of the other. Furthermore, we would not be able to establish which one is the cause and which the effect.
To understand a phenomenon it is then necessary to build a "creative" model that can in turn be suggested by different clues (among them also the statistical correlations). When we have a model we have the possible correlations, but if we have the correlations we don't have a model.
To give an example we may observe that the mail distribution in Italy is statistically correlated with the kangaroo feeding in some part of the Australian forest, but this does not mean that the one is the cause of the other. Once clarified these concepts that will prove to be very useful in the following, we move on to define what the intelligence is.

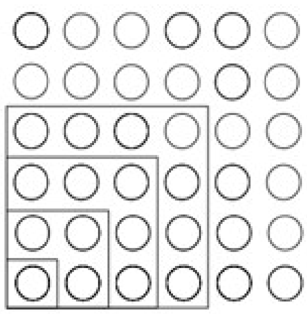
The Natural Intelligence

Defining the intelligence without addressing the vast literature on the subject [Amit 1989; Hebb 2005] is a formidable task, but in these pages we adopt a restricted point of view that will prove to be very useful for the class of problems we are considering. Aware of

the non-exhaustive nature of this definition, here and thereafter we refer to the natural intelligence as the ability to make predictions, assuming this as an operational definition, a not-comprehensive one.
We get an intelligent system if the knowledge of a phenomenon at time t enables us to predict its state at time $t + T$. Such a system is a predictor, and the larger the time T, the smarter the prediction [D'Autilia 1991]. In this sense, a mathematical formula that gives all the future positions of a planet is a top form of intelligence.

A common example of intelligent behavior is the street crossing. A pedestrian crossing a street should be able to guess the positions of the cars in the immediate future. This prediction could be difficult because it needs assumptions for the motion of the vehicles: a regular, irregular, or even random motion, but in general a very complex one. All these possibilities, together with the experience, set up a mental model that is in fact a predictor for the vehicle position while the pedestrian is crossing the street.

An apparently different example of predictive behavior is given by a theorem. When we observe that the sum of the first n odd numbers is $(n+1)^2$, we could ask if this property is always true. It is easy to check this property just looking at the following figure. In fact, adding the next odd number means to increase the side of the square by one unit. We have proved a theorem. This prediction is true forever, as well as the Pythagorean theorem, proved in the 4th century B.C. and true for all the next centuries [Høyrup 2013]. Therefore, in the framework of our definition, we say that the proof of a theorem is the best form of intelligence.



The Artificial Intelligence

To summarise the enormous amount of theoretical and technological achievements in the field of the artificial intelligence in the last 30 years, we could say that the machine learning methods are the most sophisticated way to build statistical correlations between events. Although the most relevant theoretical results on artificial intelligence were obtained more than thirty years ago [Mezard 1987], only for a few years we have had available the computational tools to transform these results into technology.

The artificial intelligence is based on the conditional probability and the estimation of the correlations between inputs and outputs. Very schematically we state that a machine learning system estimates the probability of an output on the basis of a conditional input [Goodfellow 2016]. A deep learning system also looks for nested correlations by addressing the enormous computational complexity with the power of extremely fast and efficient processors. This is a simplification, because even in this field there are differences (for example a branch of the machine learning is devoted to the automatic theorem proving) but in essence, most of the artificial intelligence that we exploit is a way to produce complex networks of statistical correlations.

Given a stimulus, the most popular systems of artificial intelligence return the probability of a response, acting as a sort of feedback system. For the great complexity of the space of the possible responses, a good training makes the machine able to respond also to stimuli for which it has not been trained. This is one of the reasons why artificial intelligence is so widespread in fields ranging from the medical diagnosis to the language translation.

However, a natural intelligent system is a feed-forward apparatus which correlate different and distant phenomena by means of a "creative behavior". Once again we give an example: let us suppose we want to guess the next line of the succession

1
1 1
2 1
1 2 1 1
1 1 1 2 2 1
3 1 2 2 1 1
...

where each line is the verbal description of the previous one: "one one", "two ones", "one two and one one", and so on. In which disciplinary field do we have to train the machine learning system to be able to predict the next line, the arithmetic or the linguistic one? And how do we suggest to the system to make the switch from the arithmetic to the linguistic? This is still an open problem in machine learning, a question dealing with the creativity and the interdisciplinary of the knowledge.

Therefore we say that there are problems that can be faced and solved with the help of the artificial intelligence and problems that can be solved only by means of the natural intelligence. The two sets have an intersection: the tasks that can be faced by both the approaches.
Proof of theorems, inductive inference, correlation among different fields are typical tasks of the natural intelligent behaviour that are currently difficult to deal with artificial intelligence. On the other hand, all the data mining problems, big data, and in general the analysis of large masses of data, can only be treated with artificial intelligence, where some predictive problems such as the street crossing can be addressed in both ways. The scheme loses sense if we realise that artificial intelligence is a tool made by the natural one for dealing with big data and in this sense it is a subset of that. The splitting of the discipline into partially overlapping areas is anyway useful if we want to develop technology, because it makes us aware how much we can rely on the different methods.

The Reality

The last concept we need to make clear before we start talking about cultural heritage is the reality. Again this is a millennial topic of philosophical discussion, but again we stick it into a simple operational definition.

When we listen to a cello player performing a Bach suite, our eardrum receives a signal which is nothing more than the air pressure variation over time. However, our eardrum receive the same signal when the music is generated by an audio file, and the brain of a musician can recreate the same sensations when it is stimulated by the reading of the score. What reality do we imagine that exists besides the signal we are listening? Of course this it is impossible to know without some additional information, and therefore we can only say that the reality is the mere signal we perceive, regardless of its source.

Once we detect a signal, our brain reconstructs the possible underlying phenomenon and a problem arise. In fact, the human brain can imagine the structure of a protein by looking at the 3D model, but it can also reconstruct a kind of "reality" by reading a story from Harry Potter or Dante Alighieri's Comedy. In the case of the proteins the mental model corresponds to a real object, in the second case to a non-real object, but in the case of Dante Alighieri it is a mixture of real and the imaginary facts. How do we evaluate its reliability when we use the augmented reality in this broad sense? The augmented reality can be misleading, but it can also add to the real world extraneous elements that lead to a better understanding of the object we are observing. This is the case of Dante Alighieri's Comedy where the historical facts are mixed with imaginary situations and it is for example the case of the 3D reconstruction of the original shape of a Greek temple. The only possible way out is to consider reality the detected phenomenon, regardless of the nature of the source that generated it. In other words, we make our own the sentence of Bernardo of Cluny "*stat rosa pristina nomine, nomina nuda tenemus*" [Neale 1864] , what is left of the rose is only its name, and we consider reality only a phenomenon that we measure by means of proper tools.
Aware of these limitations and these risks, we establish that these are the ingredients that we want to use to build an interaction tool between people and cultural heritage: artificial intelligence, natural intelligence and a clear definition of the reality we observe.

Archeology

A recent archaeological excavation (the deceased from tomb 132 in the imperial necropolis of Castel Malnome [Catalano 2009]) unearthed a skull of a man whose jaw and mandible were joined together. The study of this archaeological find makes it possible to identify a surgical intervention that allowed the individual to feed and to have a normal working activity. The understanding of this and similar finds led to an in-depth analysis of the workers nutrition during the imperial age. Furthermore the fact that the worker of tomb 132 survived opened the door to an in-depth analysis of supportive and inclusive behaviours in antiquity and to some interesting hypothesis such as the use of ramps for the transport of the sick people in the ancient healing shrines.
The artificial intelligence can be exploited to put all this information together and to create fast switches among them. The web has accustomed us to this approach: when we represent a collection of information together with the links connecting them, the numerous subgraphs of the original graph become possible different points of view. The nodes of the starting graph are the possible reconstructions of the archaeological site, the indices of the scientific literature on the subject or the related studies, where the subgraphs are the possible alternative descriptions of the subject.

Fig. 1. The skull of the tomb 132 of Castel Malnome.

The artificial intelligence is also exploited to index these graphs through an ID with a one-to-one correspondence with the object. The object detection is the access point of the graph, and the graph can be accessed from any of its nodes. By means of machine learning techniques we select the subgraphs related to the interest of the visitors or the scholars or even to address them to fields far from their own specialisation. This logical scheme is the basis of the "tadarc" project [Shazarch 2022], a tool for the recognition of the objects of the Roman forum, the baroque building of Rome or even the entire corpus of the buildings of the city of Turin, returning all the complex graph of information related with that object. In this approach for example, the recognition of the Divo Julio temple in the Roman Forum can lead, on the basis of the visitor's interests, to a philological reconstruction of the temple, to the text of Appiano on the death of Caesar [Appiano 2015] or to the model of Marlon Brando-Marco Antonio in the film by Joseph L. Mankiewicz [Miller 2000].

Conclusions

The enormous technological evolution of the last decade gave us the tools to put together information that comes from different disciplines. By means of the machine learning this information can be used to observe the world on different spatial and temporal scales: from the microscopic to the macroscopic one. At the same time we have the possibility to put together and make accessible these data without distorting the content. This approach allows us to to evolve all the theoretical studies of the last decades into a technology that could change definitely the way the people interact with the history.

References

Amit Daniel (1989). *Modeling Brain Function: The World of Attractor Neural Networks*. Cambridge: Cambridge University Press.

Andrianaivo Louis Nantenaina, D'Autilia Roberto, Palma Valerio (2019). Architecture recognition by means of convolutional neural networks. In *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W15, 2019, pp. 77-84.

Appian John Carter (2005). *The Civil Wars*. London: Penguin Books Limited.

Catalano Paola, Benassi Valentina, Carla Caldarini (2009). Attività lavorative e condizioni di vita della comunità di Castel Malnome (Roma, I-II Sec. D.C.). In *Journal of History of Medicine, Medicina nei secoli - Arte e Scienza*, 22(1-3), 2010, pp. 111-128.

D'Autilia Roberto, Guerra Francesco (1991). Qualitative Aspects of Signal Processing Through Dynamic Neural Network. In De Poli Giovanni, Piccialli Aldo, Roads Curtis (eds.). *Representations of Musical Signals*. Cambridge: MIT Press, pp. 1-16.

Goodfellow Ian, Bengio Yoshua, Courville Aaron (2016). *Deep Learning*. Cambridge: MIT Press.

Hebb Donald Olding (2005). *The Organization of Behavior: A Neuropsychological Theory*. London: Taylor & Francis.

Høyrup Jens (2013). *Algebra in Cuneiform: Introduction to an Old Babylonian Geometrical Technique*. Berlin: Max-Planck-Institute for the History of Science.

Marinari Enzo, Parisi Giorgio (2004). *Trattatello di probabilità*.
https://www.phys.uniroma1.it/biblioteca/web_disp/d3/dispense/marinari-parisi--prob.pdf (01 July 2022).

Mezard Marc, Virasoro Miguel Angel, Parisi Giorgio (1987). *Spin Glass Theory and Beyond*. Singapore: World Scientific.

Miller Anthony (2000). Julius Caesar' in the Cold War: The Houseman-Mankiewicz Film. In *Literature/Film Quarterly*, 28 (2), 2000, pp. 95-100.

Neale John Mason (1864). *De Contemptu Mundi*. London: J.T. Hayes.

Shazarch Blog (2022).
https://www.shazarch.com (01 March 2022).

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