Archaeology and the application of artificial intelligence : case-studies on use-wear analysis of prehistoric flint tools

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8 Synthesis

8.1 Introduction

The main goal of the present study has been to experience and subsequently demonstrate the potentialities of artificial intelligence approaches, in particular knowledge based systems, for archaeology. For practical reasons I concentrated on one knowledge domain, use-wear analysis on flint artefacts. The aim was to develop a truly operational application.[1]
A substantial part of this study has therefore been devoted to the formalization of the knowledge that is involved in this method and to subsequently put it at the disposal of non-experts.
Two applications were built, an expert system (WAVES) and a neural network prototype (WARP). The aim of developing two applications was to reveal the benefits and difficulties of the two approaches from a methodical point of view and to demonstrate their differences. The previous chapters addressed the methodical aspects of these case-studies. It has for instance been shown which operations are required, what aspects should be taken into account and what difficulties can be expected when developing a knowledge-based application.
In this chapter, I will return to the principal question of this study: the benefit of artificial intelligence techniques, especially knowledge-based systems, for archaeology. In chapter 2 the state of affairs regarding the role of these systems in archaeology was discussed and it was observed that they have not yet reached the prosperous future that several researchers expected them to have (*e.g.* Gardin *et al.* 1988: 219). Despite the fact that it has been demonstrated that useful knowledge-based applications can be built for archaeological purposes and that there are many potential uses, their assumed limited functional abilities still keep archaeologists inconclusive on their value. Therefore, I first of all want to discuss what they offer us that makes the endeavour of their development worthwhile.
This question will be answered by looking at the *added value* of knowledge-based systems for archaeology. In this three levels are discerned. The first level at which archaeologists can benefit from them is at the user-level. In order to demonstrate this I will go into the particular benefits of expert systems and neural networks in more detail (paragraph 8.2). The second level is at the methodical level, *i.e.* of the involved subject. Studies like the present can stimulate the development of the knowledge domain, because the inevitable elicitation, analysis and modelling of the involved knowledge reveal its lacunae and ambiguities. Moreover, the limitations of the resulting application show the methodical aspects that are eligible for improvement and in which directions these may be found. As this aspect has been discussed in previous chapters, it will not be addressed again. The third level at which we can benefit from knowledge-based applications concerns archaeology as a discipline. In particular in the context of the commercial society that archaeologists have to deal with, they can offer us interesting possibilities (paragraph 8.3).
The subsequent question is *what* archaeologists can do to benefit more from knowledge-based systems in the future.
I have previously stated (chapter 2.4.3), that I do not believe that knowledge-based systems, in particular expert systems, lack popularity because of their limited functional potential. In my opinion, we simply have not been developing enough useful applications and have had too few attention for their social acceptability. Consequently, both a different approach from system developers and a different attitude from end users is needed (paragraph 8.4).

8.2 The added value of expert systems and neural networks

8.2.1 Expert systems

The added value of any application can best be assessed by comparing its task with the traditional way in which it is carried out. Expert systems can be used in many ways, but it would go beyond the scope of this paragraph to discuss the added value of all of these. Therefore, I will focus on the prime task of the application in this study: computer-assisted-instruction. In this realm expert systems compete with traditional means of teaching: books and manuals, traditional computer programs and, of course, human teachers. In comparing a computer program with a human teacher, it should first of all be stressed that a *virtual teacher* can never replace a human. Obviously, personal contact between students and teachers will always remain very important. Nevertheless, computers will increasingly become useful instruments for initial teaching, practising and as sources of

reference. Even on highschools there already in an increased interest for virtual teaching.
From the perspective of a student, an important reason for the growing popularity of virtual teaching is that, in contrast with books, it offers interaction. It can explain the obtained interpretation, by reconstructing the reasoning process that was followed, or react immediately to mistakes. Moreover, it not only shows why a particular conclusion can be drawn but, also why other conclusions would not be valid. Compared to learning from a book this may enhance the method of teaching and makes the learning process more vivid, especially if advanced techniques of moving images and sounds are included.
Furthermore, a well-designed knowledge-based application offers knowledge orderly and consistently and can offer the possibility to evaluate a hypothesis. A good teacher would do the same, of course, but could never offer this service to every student in the same constant and consistent manner. Indeed, consistency is another major advantage of virtual teaching. Though teachers may not always realize it, their available time, moods, personal preferences, etc. may play a role in the manner in which they supervise students. An automated system, however, has no moods and will treat each student in exactly the same way. It will never become impatient if a question is asked over and over again. Moreover, the artificial expert is available and willing at any moment. Since it can be duplicated infinitely, several people could call upon its services simultaneously.
Yet another advantage of virtual teaching is that it personalizes the learning process. Students can get total control over the pace of their learning process and can concentrate as much as they like on the aspects they experience most difficult or like best. It also enables students to work together on the same assignment and to compare their results.
From the point of view of a teacher, the use of an expert system can also have advantages. First of all, it may enlighten his or her educational task. It not only offers a capacity increase since more students can be practicing simultaneously, but teachers also need to supervise them less if they can practise the basic phase of their training by means of the computer. As a consequence, the expert can save precious time which can be spend on research. In its turn, this research may yield additional knowledge by which the method and thus the system can be optimized. Furthermore, it requires less effort to keep a knowledge-based system up to date than a guide book. Irrespective whether he or she does it personally or contracts it out.
An additional advantage of virtual teaching is that it facilitates the monitoring of the progress of an apprentice. By evaluating the given descriptions and obtained interpretations, a student's weak spots and mistakes are discovered immediately. This allows to correct his or her learning process in an early stage.
It also guarantees that all students get an identical initial training and are guided consistently. Their learning process will not be affected by absence or time pressure of the teacher.
Finally an expert system application can also be compared with a traditional algorithmic computer program. In many cases educational programs have been built by means of traditional programming methods. In many cases, they do not show significant functional differences from 'real' expert systems. The prime added value of the latter approach, however, is its modular structure. It is intrinsic to the separation of its components that it can manage more complex tasks without becoming totally opaque and unmaintainable. This also makes it more flexible and, for that reason, more durable.

8.2.2 NEURAL NETWORKS

It is slightly more difficult to give a clear outline of the added value of neural networks as compared to expert systems. Not because they are less useful, but because they handle tasks in a way that is less comparable with a traditional approach. Since they are very suitable for tasks that require generalization or association, or for revealing patterns in large quantities of data, they can best be compared with a human being or with a statistical package.
Compared with the human brain, neural networks are of course only a rough and artificial copy. They are hardly able to perform on the same level. On an 'intelligence' scale, expressed as a combination of processing speed and the amount of neurons, they may reach the level of 'intelligence' of a cockroach only (Lawrence 1991: 128). Nonetheless, in comparing them with a human in solving particular tasks they certainly have some added value. First of all, neural networks are much better in *data mining*. They can find relationships between the variables in large amounts of data or complex problems that humans are unable to detect (*e.g.* Grupe & Owrang 1995; Adriaans & Zantinge 1997).[2] This is because they can easily detect and subsequently ignore redundant information. Furthermore, they are better in *optimization*. They can find an acceptable solution without having to make various time-consuming calculations. In general these solutions will be better than those of a non-expert, though not necessarily better than those of an expert. Another advantage is their objectivity. For instance, they recognize patterns on the basis of calculations rather than on subjective interpretations like humans do. Therefore they will make less mistakes in recognizing patterns that are identical to the patterns they have learned. Like expert systems, they perform consistently and are easily duplicated. They do not get bored, tired, sick or unconcentrated. Under all circumstances all input data will be assessed equally. Furthermore they are more easily trained. It takes only hours or days to train a network, while it may take months or years to train a human analyst to reach the level of an expert.

In comparison with traditional programs like conventional statistical pattern recognition methods, one of the added values of neural networks is that they react flexible to incomplete data. It allows for interpretations if part of the input data is unknown. Moreover, they have a much higher processing speed. Since they only consist of a simple data-matrix (representing the weights of the connections between the neurons), one session of the analysis process only consists of a calculation of neuron activities. Consequently, they can present their interpretation within merely a fraction of a second.
A final advantage is that neural networks are more easy to construct. Since they only have to be fed with examples there is no need to construct a complex program. Consequently, they are more easy to maintain. By simply adding more experienced examples to the training set and by repeating the training process, the network can be kept up to date. If necessary, even at a daily basis.

8.2.3 EXPERT SYSTEMS VERSUS NEURAL NETWORKS?

The main reason for comparing an expert system application with a neural network in this study, was the supposed superiority of the latter regarding its functional ability and social acceptability (Gibson 1992). In the introductory chapter, it was already indicated that this statement was not based on a comparison of two similar applications and on test results. After having presented and tested two similar applications, we are now in a position to evaluate Gibson's initial assumption.
A first conclusion is that both approaches are so different from each other that we are in fact comparing apples with oranges. Although they are both knowledge-based systems, they are equipped with different knowledge representation and reasoning methods. Therefore they are not suited for the same tasks. For this reason, it is useless to conclude that one method is superior to another. Such a conclusion would imply that a human who is specialized in reasoning through association and generalization is superior to a human who reasons through deduction.
Furthermore, if neural networks would function better than expert systems, a comparability test would have clearly demonstrated this. However, it was shown in chapter 7.3 that neither one achieved significant better results than the other in a comparable situation. The fact that "*…their performance at the edge of their knowledge is* ***far*** [my emphasis] *superior to that of the expert system.*" (Gibson 1992: 265) could not be acknowledged by the test results either. Indeed WARP generated interpretations in all 11 cases that WAVES could not. But, since 8 out of these 11 were wrong, it is clear that the answers that are based on the fringe area of its knowledge are not always reliable. This can be explained by the fact that a neural network will always generate an answer, even if this means that it has to make a rough estimation. The question is whether in all situations an educated guess is preferable to no answer at all.
Another argument for the perceived superiority of neural networks is that they have the capacity to formulate their own representations of the expert's reasoning processes (*ibid*. 265). They do not require a knowledge model and may therefore be able to handle more complex knowledge. Indeed, this is true, but the question is whether this is always an advantage. It brings along some major drawbacks as well because it makes a neural network a *black box* which is unfathomable for both system developers and end-users.
As a consequence, the user does not know what exactly the network has 'learned'. This may cause unexpected interpretations.[3]
Surely, such limitations affect the social acceptability of neural networks. According to Gibson this may be a problematic aspect of expert systems because "*People tend to fear technology when it is professed to have qualities that humans have*." (1992: 264). Unfortunately, this does not exclusively concern expert systems. In fact, it may apply even stronger to neural networks: their image may be even *worse* than that of expert systems because they are professed to have qualities that resemble human reasoning even better than expert systems. Moreover, if the arguments of Gibson are followed literally, neural networks may turn out to be less popular than expert systems because they allow even less human interference. In my opinion the only two characteristics of neural networks that favour their social acceptability as opposed to expert systems, are their development ease and processing speed (see paragraph 6.3).
To conclude, I believe that there is no reason to assume that either approach is superior to the other. Since each approach has its advantages and disadvantages, it is mainly the *selection of the appropriate technique* in combination with the *composition of the involved knowledge* that determines the functional ability and social acceptability of an application. In comparing them, we therefore ought to focus on the actual abilities of *applications* instead of on the potentialities of *approaches*, because solely achievements count, not promises which are delivered with software packages.

8.3 ADDED VALUE OF KNOWLEDGE-BASED SYSTEMS FOR ARCHAEOLOGY

In this thesis I have hitherto not referred to the more general benefit of applying knowledge-based systems for our discipline, yet archaeology could profit from them in various ways. In particular in the context of the commercialization and increase in scale that archaeology is nowadays confronted with, they may gain importance. Both academics and field archaeologists experience increasing time constraints. In the past, the existence of a few experts was sufficient to educate all others that were active in their knowledge domain and one could appeal to their knowledge when necessary. In this way, expert knowledge was further distributed. Since recent years, however, research must be increasingly fitted in narrow time schedules of real-estate developers and education programs must be completed in less time because of shrinking bursaries. Simultaneously, the work load increases due to positive developments like a growing public interest in archaeology, a growing number of students and to policy changes, like the Malta-convention. The educational and research capacity, on the other hand, cannot keep pace since the number of experts has not grown likewise.

As experts are less available, an increasing number of archaeologists tries to make its own analyses of all find categories. In the best case, they are guided by a book or an article, but they have to decide on the basis of illustrations. This implies that everybody is doing this in his own way and it is inevitable that everybody may put his accents differently. As a result, information may become less accurate and less comparable.

Consequently, it becomes increasingly important that we enlarge both our educational and analysis capacity through other means. In this respect, two concepts may be important, *efficiency* and *knowledge democratisation*. The latter implies that through the use of computers data, information and knowledge are more easy to transmit, share and access (Huggett 1993, 1995). In the 1980's it was tried to adapt to this evolution by putting as much information as possible in analytical devices like statistical packages and Geographical Information Systems. This helped to diminish bottlenecks in the analyses, but it also made us realize that the main concern of this kind of democratisation is *quality control*. The results were not always as useful as would be wished. It turned out that the quality of the information input in these systems highly determined the quality of their output.

Knowledge-based systems can exactly help on these issues, since their main benefit is their ability to store our expert knowledge and to make it accessible to other people. Especially in the area of find analyses and classifications they may be of considerable value, because they can provide an archaeologist with a device that helps to obtain deducible and comparable interpretations. Obviously, this may not only be useful for academic research or education, but surely also for archaeologists in field units. In short, knowledge-based applications not only allow us to optimise the exploitation of our expertise, but they also enable us to keep control over the quality of the knowledge that we distribute.

8.4 Recommendations

8.4.1 A DIFFERENT APPROACH OF FUNCTIONALITY

In having answered the question *why* we would want to apply knowledge-based systems in archaeology, the next question is *how* we can improve their popularity. First of all, I believe that system developers have to select practical subjects. Hitherto, the main argument for their lack of popularity in archaeology was that our knowledge would be unsuitable for this approach. Its subjective and intuitive nature complicated its formalisation, because the available knowledge representation methods had insufficient expressive power; the inference mechanisms allowed too little variation and were too restrictive to incorporate aspects like uncertainty, historicity etc. (*cf*. Wilcock 1986; Vitali & Lagrange 1988; Gibson 1992). In my opinion, these obstructions or limitations are not as absolute as they may seem. Most of the case-studies from which these conclusions were drawn, involved rather complicated subjects because they had a purely scientific aim. For instance, the main interest of Gardin *et al*. was the *art of reasoning*: they wanted to find out whether expert systems could be applied satisfactorily for the schematization of discourse (1988: 211). Their case-studies involved the translation of argumentations that scholars use to discover or prove the meaning of archaeological remains, such as that of a partly recovered fortified garden from the Middle Ages (*ibid*.: 150) and that of Roman amphorae (*ibid*.: 126).

Such studies certainly yield interesting information, but the conclusions that are drawn from these on the functional ability of knowledge-based systems only count in that particular context. They do not necessarily count for applications that were built for other, more practical, purposes. Therefore, I am convinced that part of the reservations towards knowledge-based applications can be taken away if we employ these systems for methodical tasks that are clearly defined and of which the required knowledge has crystallized. We should develop applications that may serve as practical tools for a larger group of users than specialists only, like for instance devices for virtual teaching and find identification. Instead of using an expert system to *establish* a typology for Roman amphorae (Gardin *et al*. 1988: 126), we should use a typology of Roman amphorae to make an expert system.[4]

If we look at them as practical aids, many more subjects besides use-wear analysis can be handled by knowledge-based systems. Other examples are the analysis of human or animal bone, teeth and DNA, the determination of botanic remains, the classification and dating of ceramic material or other guide artefacts from all kinds of archaeological cultures such as fibulae, coins, etc. In fact, our profession has an abundance of potential issues.

An additional advantage of this kind of applications is that they can easily be adapted to other subjects that require similar reasoning processes. For instance, the decision rules that were used in the present application for the analysis of use-wear on flint artefacts, can fairly easily be adapted for the analysis of wear traces on obsidian or on other kinds of stone material.

If employed in this manner, we could also profit economically from these identification tools, because they improve our efficiency and, therefore, our productivity. They can help to get results of finds analyses more quickly when we would employ them during or immediately after an excavation campaign. Additionally, excavation reports could be produced more quickly as well. It must be stressed, however, that it may not always be possible or recommendable to have this kind of analyses carried out by layman on the subject. It is advisable to deploy experienced analysts that are supervised by an expert, as we have seen that the quality of the input determines the quality of the output.

Alternatively, one could think of a scenario with specialized expertise bureaus. These could consist of a subject specialist accompanied by a number of analysts, which apply the experts knowledge by means of knowledge-based systems. Supervised by an expert, the assistants could be making production on less complicated analyses, while the expert himself would be called in for difficult cases. An advantageous side-effect of such a development would be an increasing amount of high quality archaeological information, because capacity increases may eventually accomplish that the standard procedures for site investigations include a broader spectrum of analyses. For instance, it may help use-wear analysis to become an integrated and indissoluble aspect of the investigation of Stone Age sites.

Whatever subject we choose, its selection must be based on a cost-effect calculation. One must find a balance between the complexity of the application and the number of potential users. On the one hand, it is advisable to develop small applications, because complicated systems may not only take a tremendous effort to develop, they may also be too difficult to understand and to handle by a user and too complicated to maintain and may turn out to be unacceptably vulnerable to the regional differences that are characteristic for archaeology. On the other hand, the subjects must not be too specialized. Sufficient users must be willing to buy the application or be willing to share its development costs. Thus, an optimal *scale* of an application will reduce financial risks.

Apart from the functional disabilities, a second argument that archaeologists have used against knowledge-based systems, is that they would be too difficult to develop. Again, this argument has to be assessed in its context. Indeed, in the early days their development was exclusively preserved for mathematical grounded archaeologists, which are never abundantly available. However, in this respect the type of tasks that we select is of crucial importance as well. It is obvious that in the development of ‘scientific’ applications that have hitherto been developed some serious problems were encountered. It is certainly a hazardous task to translate complex discourses by means of representation methods like logic or decision rules, but I have tried to demonstrate that well-defined and straightforward methodical deductions are less difficult to capture.

The idea that knowledge-based systems would be too difficult to build, not only relates to the kind of tasks they were employed for, but also to the kind of development tools they had to be made with. In the early 1980’s, solely complicated and user-unfriendly computer languages were available for this task. Fortunately, this has changed rapidly. Expert system technology now offers a larger variety of knowledge representational abilities, application building facilities, and abilities to communicate with the environment, *i.e.* with other programs or other devices. Many of these techniques have been made accessible for a large group of users by means of user-friendly packages that are commercially available. For instance, so-called expert system shells enable application building without having to program complex procedures (see also chapter 3). As a result, application development does not require an awful lot of knowledge on hardware or software anymore. It has become within the reach of archaeologists which are not very experienced with sophisticated computing techniques to build their own simple applications.

This does not mean, however, that each archaeologist will — or has to — be able to construct his or her own applications, but it surely has some advantages to have applications developed by knowledge engineers with an archaeological background, or vice versa. These engineers do not need an extensive introduction to the knowledge domain. Consequently, this prevents communicational misunderstandings, enables an engineer to work independently and saves the expert from numerous time-consuming consultations. Furthermore, such engineers are likely to deploy their experience for the benefit of other archaeological applications, while the investment in external knowledge engineers will perish once the assignment will be completed.

8.4.2 CARE FOR SOCIAL ACCEPTABILITY

Even if we would manage to improve the functionality of knowledge-based applications, this would not guarantee their success in archaeology. If we want our applications to become socially and academically accepted, we have to interest potential end-users. A first recommendation is to present *results*. As long as teachers or field archaeologists hardly ever see a successfully operating application, they keep vague ideas of their abilities and they will not start using them. Up till now, however, scanty attention has been given to application fulfillment, let alone to performance evaluation and test results. Almost a decade has past since Gardin *et al*. (1988) presented their book on expert systems, but we still have hardly left the demonstrational phase.

System developers did present the abilities of their *prototypes*, but these do not give a comprehensive image of their true potential. Only objective results of operational applications enable future users to assess the abilities and limitations of such systems, because this is the only stage in which these really emerge.
A second recommendation that may help to improve their social acceptability is to take the wishes of future users into account in the development process. It has been experienced that archaeologists sometimes have a reluctance to accept the work of someone else and to integrate it in their own activities (Brandt 1993: 35). Therefore, we should involve the end-user as soon as possible in the development process. Furthermore, applications should be as user-friendly as possible in order to enable them to be used by archaeologists that do not particularly enjoy computers. Surely, the kind of task we select will be of influence as well. Applications on issues that are not subject to debate and which are useful for many people, will be more easily accepted than on systems that handle controversial issues.
Besides test results, user friendly applications and generally applicable tasks, a fourth key word for improving their social acceptability is *integration* with information technological devices that have already become established tools. Large amounts of data are available in digital format and are waiting to be extracted in a useful manner. Knowledge-based systems could be used as front ends to geographical information systems or for other data storage and handling means. In fact, they may be combined or incorporated with statistical packages, multimedia applications, databases, etc. For example, we could add a knowledge-based *front end* to national information systems like the Dutch ARCHIS, in order to improve their accessibility for external users, such as municipal functionaries.
A final aspect I would like to mention in this context is *promotion*. If we want our applications to be accepted and applied, we must make our colleagues aware of their existence. Moreover, they should have easy access to them. One way of doing this could be through the Internet: we could think of an 'archeological software shop' or of giving students on-line access to educational applications.

8.4.3 CHANGE OF ATTITUDE

In the previous paragraphs I pleaded for a different approach by application developers. However, also end-users need to develop a different attitude towards knowledge-based systems. Gardin *et al*. already realized that some fundamental changes in the humanities were a first condition for knowledge-based systems to play a fundamental role in archaeology (1988: 226). In my experience, some archaeologists have developed a dualistic attitude. On the one hand, they distrust high-tech tools because they experience them as rivals, while on the other hand they reject them because such applications can never live up to their expectations.
In the first place, I am convinced that most of the rejections are based on scepticism that is fed by fictional ideas rather than by experiences with operational applications (Van den Dries 1993: 245-248). The latter can hardly be the case, because few operational systems exist. Fictions especially circulate about their functional abilities: why should we want an expert system to *surpass* the expertise of an expert (Gibson 1992: 263)? In my opinion, the aim of their application is not to imitate human reasoning in all its details. We therefore have to abandon the idea that they have to function equivalently to a human expert or that they can contain *the* answer. Our main interest should be to simply turn them into useful tools.
Consequently, we will also have to redefine the meaning of a 'successful' application. We have to stop striving for completeness, not only because a computer model can only represent a small aspect of the real world situation, but also because it is absolutely unnecessary. In my opinion, a knowledge based application is already successful if it helps employing knowledge more efficiently and if it makes it accessible to non-experts.
Secondly, the fear that knowledge-based applications may substitute humans or endanger the work or position of an archaeologist is based on fictional ideas as well. Several computer scientists (*e.g*. Feigenbaum & McCorduck 1983) as well as philosophers specialized in logic (*cf*. Copeland 1993) are decisive about the fact that artificial intelligence is not the equivalent of human intelligence. Computer programs can simulate predefined reasoning processes but certainly not generate intelligence because they improvise rather than reason. Hence, artificially intelligent archaeologists are predominantly artificial, not intelligent.
Obviously, the only competence of an artificial intelligent application is to serve as an assistant. It cannot replace an expert. On the contrary, it rather consolidates the expert's position. Since it enables experts to work more efficiently, it also enables them to increase their capacity and to expand their knowledge. Subsequently experts can fully exploit those abilities which are valued most because they cannot be simulated by a computer. Calling upon a knowledge-based application should not be interpreted as a motion of no confidence, because the ability of the expert is never questioned. In this respect, we can compare the role of a knowledge-based system with that of an automatic pilot or a cruise control. Such applications can yield considerable efficiency, but you only apply them when possible and when it is for your own ease. The risky parts of a trajectory are left to be solved by a human. Moreover, it is unrealistic to suggest that a cruise control can replace a driver. Nobody switches it on because he or she is unable to drive himself. On the

contrary, only an experienced driver is able to handle such a device accurately and safely. Similarly, only an expert or experienced analyst can decide whether and when the device will be of use.

Thus, if we think of them as storage facilities that are more efficiently constructed and therefore more broadly usable than some other traditional computer programs, I do not think there have to be major objections towards these applications anymore.

8.5 Concluding remarks

With the presented case-studies, I have tried to demonstrate that most of the scepticism of archaeologists towards the use of knowledge-based systems needs to be revised because they can indeed be useful for archaeological purposes. They offer a means to formalize and model subjective expert knowledge, they can be employed for both research and educational purposes. Moreover, they provide a (scrupulous) means for revealing deficiencies within our knowledge and for democratising it, *i.e.* they make it accessible and applicable for non-experts.

Regrettably, we have hitherto neglected to exploit the unique facilities that knowledge-based approaches offer us. We have been too busy discussing their merits to have time to actually employ them for our own benefit. I have tried to illustrate that it is only by building practical applications and by demonstrating their results that archaeologists will witness the abilities of these approaches and acknowledge that there is a broad range of potential applications.

It is exactly due to this abundance of eligible issues, however, that I have stressed the necessity to select both the employed automated approach and the subject with care. Regarding the selection of a technique, I have argued that neither expert systems nor neural networks are more useful than the other as long as the right one is used for the right reasons. However, it was also demonstrated that neither technique will always offer the solution for a problem, just as no human expert can. Consequently, the utmost benefit of artificial intelligence may be lying in a combined use of two or more approaches. This may offer various, yet unexplored possibilities especially for archaeology, since our discipline often involves several types of knowledge and discourse. With reference to the selection of a subject, it was concluded that analytical and methodological subjects, *i.e.* practical issues, have the best chance of being successfully automatized. The involved knowledge should be easily accessible and the domain experts should be open-minded and willing to cooperate with the development of the application. Additionally, applications should not be too large and their task should be circumscribed in order to facilitate their development, use and maintainance. Eventually, only applications that fulfil a need can be expected to become the assistants archaeologists value.

notes

1 WAVES is operational since 1994 and being used at five different departments in Europe and Australia.

2 It must be stressed that despite the fact that a neural network can be an interesting tool for handling complex data, complexity should not be the main argument by which a subject is selected to be simulated by means of a neural network. The main criterion is that there is a sufficient number of examples to educate the network.

3 One of the problems may be that a network may have learned to distinguish the examples from each other by means of properties which are background noise and have nothing to do with solving that particular problem. Furthermore, if a network structure is not well designed, for instance if the hidden layer is composed of too many neurons, it may learn the examples by head without being able to analyze any new problem (Lawrence 1991: 123). Another well-known example of a self-willed network is a robot that had been trained to avoid obstacles. When it was finally tested it refused to make any movement at all. It had 'concluded' that the best way to prevent a collision was simply not to move at all.

4 Even a neural network application would not be able to *establish* an adequate typology. It can help to fit other examples in a classification, but it cannot be employed to validate whether the training examples itself, *i.e.* the premises of the classification, are correct.