An expert system for the ageing of a domestic animal

D. R. Brough* & N. Parfitt**

* Department of Computing, Imperial College,
180,Queens Gate, London SW7.

** Exeter University

Abstract

The interpretation of artifacts uncovered during a dig may require considerable specialised knowledge. Such expertise may not be immediately available to archaeologists in the field and thus incorrect interpretations may be made due to lack of important information. This paper applies current expert system techniques to the problem of ageing horse remains from information supplied by the examination of teeth to illustrate the potential for wider application of such techniques to archaeology.

The archaeological problem

All evidence is important for the assessment and interpretation of a dig and ageing of animals can give useful information on the pattern of behaviour of the settlement being investigated. It may be possible to infer from even a single tooth the age and species of an animal. However, reliable ageing can require considerable specialist knowledge. This expertise may not be available at the dig which may cause useful information to be lost and at worst incorrect conclusions to be drawn about the excavated settlement.

The aim of this paper is to illustrate with the aid of a case study the feasibility of capturing expert knowledge for the ageing of one particular domestic animal, the horse.

There are several levels of difficulty involved:-

The literature, in common with similar specialist areas, has a host of specialist jargon which makes understanding difficult for the non-expert, so some kind of glossary and explanation facility is essential.

Although some idea of age can be gained from even a single tooth, the most accurate assessment is only obtained when several teeth are available, preferably still embedded in the jaw. Accuracy of age assessment is greatest for specimens from young and adolescent animals.

Methods of ageing used

The first stage in ageing is to consider the state of eruption of the teeth for example determining how many have come through and whether they are deciduous (milk) or permanent teeth.

The next stage is to consider the state of wear of the teeth. Due to their structure the incisors in particular pass through a series of stages of wear which show visible signs. For example the incisors have a long crown with a central hole called "the mark" or infundibulum which is filled with cement. This is gradually worn down until about 4.5 years after eruption it disappears from the biting surface of permanent incisors. Similarly there is a property called the star which appears about 2.5 years after eruption.

Another indication is the shape of the table or biting surface of the tooth. As the cross section of the tooth varies considerably from crown to root the table changes shape with age. (see figure 1)

Finally there are indications of greater age such as galvayne's groove which appears at about age 10 and evidence for old age in decay and high polish of the teeth

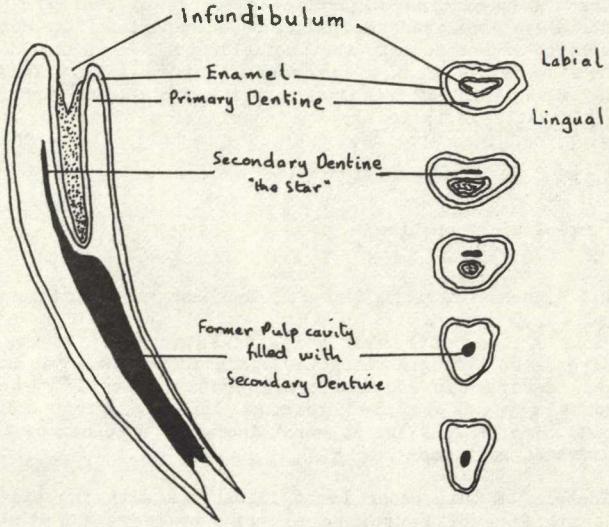

Figure 1 - diagram of structure of incisor of the horse
(after Silver)

problems of accuracy

There are various prerequisites for accurate assessment of age. These are:-

1/ Knowledge of the relation between ageing indications and age at the time the animal lived rather than just the modern species. In practice the modern age characteristics are used with adjustments. However this is an area in which even experts can differ. (compare refs 1 and 2)

2/ The plane of nutrition must be known and also the type of soil and herbage. This is because, for herbivores, short grass on sandy soil causes much more wear than lush herbage on soft soil with low silica content.

Concepts of Expert systems

The term expert system is used to describe a program which encodes an expert's knowledge, can solve problems as well as an expert and which can explain the answers it gives in terms of the knowledge it has used. Typically, the expertise is described as a set of rules in a form intelligible to the human expert.

An important aim is the ability to encode incomplete (and possibly vague) expertise in a form intelligible to the expert rather than the computer expert. The process normally procedes iteratively, by encoding a subarea of the knowledge and testing its performance against the human expert on some given test data.

Inexact or fuzzy information can be handled by associating a "confidence factor" with the knowledge and providing general rules defining the degree of certainty of the conclusions of a rule with the degree of certainty of its conditions.

Some of the most useful applications of expert system techniques have been in medicine or engineering design areas where errors could have lethal consequences and "accountability" is of prime importance. This is provided both by the intelligibility of the rules to human beings and the various explanation facilities available on most systems.

The illustrative expert system

We have chosen the ageing of the domestic horse since the knowledge required is available and not too complex.

1/ Provision of background information

The first step is to define a glossary of the more technical terms relating to the dentition of the horse. some examples are:-

deciduous means milk
resorbtion means root is sharp due to pressure from underlying permanent tooth
dentition means teeth
diastema means natural gap separating certain teeth
galvaynes-groove means longitudinal groove appearing on the labial surface of the maxilliary permanent 3rd incisor at the gum margin about the age of 10
labial means towards the lips
maxilla means upper jaw
table means the biting surface of the tooth
deciduous means small and white, with distinct neck, arranged in semicircle in jaw, often with signs of resorbtion
permanent means long curved with dirty white enamel, grooved on labial aspect and has considerable change of cross section from crown to root

2/ Building a knowledge base of facts

We must now provide the core facts about the time periods during which the various teeth are present in the jaw.

```
central deciduous incisor   present-from   0   to 2.5
          ie the first milk incisor is present at birth and is ejected by
              the permanent incisor at age 2 1/2 years

lateral deciduous incisor   present-from   0   to 3.5
corner  deciduous incisor   present-from   0.5 to 4.5
central permanent incisor   present-from   2.5 to infinity
lateral permanent incisor   present-from   3.5 to infinity
corner  permanent incisor   present-from   4.5 to infinity
```

3/ Addition of general rules about wear marks

We must now give the rules about the special wear marks such as the infundibulum, the star and galvaynes groove.

```
infundibulum on <tooth-n>   disappears-at   <age>+4.5
       if <tooth-n> identified-as <type-of-tooth> and
          <type-of-tooth> erupts-at <age> and
          <type-of-tooth> is-permanent and
          <type-of-tooth> is-incisor
```

This states that the infundibulum on permanent incisors disappears 4.5 years after eruption.

```
star on <tooth-n>   appears-at    <age>+2.5
       if <tooth-n> identified-as <type-of-tooth> and
          <type-of-tooth> erupts-at <age> and
          <type-of-tooth> is-permanent and
          <type-of-tooth> is-incisor
```

This states that the star or secondary dentine appears 2.5 years after eruption for permanent incisors.

```
full-wear on <tooth-n>    appears-at    <age>+0.5
       if <tooth-n> identified-as <type-of-tooth> and
          <type-of-tooth> erupts-at <age>
```

This says that all teeth take about 6 months to come into full wear after eruption from the gum.

```
galvaynes-groove on <tooth-n>   appears-at   10
       if <tooth-n> identified-as  corner permanent incisor
```

This rule states that galvaynes groove appears on the 3rd permanent incisor at age 10.

4/ Rules relating facts and rules to age

The next stage is to specify the rules relating the type of tooth with the allowable age range:-

```
<tooth-n> evidence-for <age-range>
      if <tooth-n> identified-as <type-of-tooth> and
         <type-of-tooth> present-from  <age-range>
```

This rule just states that a tooth is only evidence for an age range which is consistent with the presence in the jaw of a tooth of that type.

```
<tooth-n> evidence-for  <age> to infinity
       if <indication> on <tooth-n>   appears-at   <age> and
          <indication> actually-present-on <tooth-n>
<tooth-n> evidence-for   0 to <age>
       if <indication> on <tooth-n>   appears-at  <age> and
          <indication> not actually-present-on <tooth-n>
```

These rules say that if an indication normally appears at a certain age then if it is actually present on a tooth then the actual age must be greater otherwise it must be less than the certain age.

There are similar rules for the disappearance of indications at certain ages.

5/ Interrogating the system

It is now possible to find out what age range(s) a particular tooth is evidence for, by using the query:-

```
Which(<age-range>
     tooth (<labeled-tooth>) and <labeled-tooth> evidence-for <age-range>)
```

Where various assertions giving information about the type of each tooth and the presence or absence of features such as the infundibulum and galvayne's groove have previously been added to the data base. However there would be as yet no explanation facilities or automatic gathering of data from the user.

6/ Providing full expert system facilities

An expert system shell in logic [3] has been developed by Peter Hammond and Marek Sergot of Imperial College which allows queries such as the above to be run whilst at the same time giving the ability to have answers explained. In addition certain rules can be defined as "askable" which has the effect that if the system has no information in its internal data base for one of those rules then it will query the user for it and also save the answer(s) for future use. The system will automatically generate an appropriate query but facilites are available to allow the system implementor to specify a "sugared" form of any query if required and also to provide validity checks on input. These validity checks are also used to indicate to the user the correct form of response if there is any uncertainty. Instead of replying immediately to a request for information the user is allowed either to ask why the request has been made or to interrogate the data base to help him decide how the request should be answered.

Example of an interaction with the teeth expert system

Which(x tooth(y) & y evidence-for x)

```
please give label X for tooth?
    Answer is  A

is tooth A deciduous or permanent?
    Answer is  which(x deciduous means x)  {ask question about meaning
                                            of deciduous before answering}
=== > milk
=== > small and white, with distinct neck, arranged in semicircle in jaw,
 often with signs of resorbtion

is tooth A deciduous or permanent?          {questionrepeatedby system}
    Answer is  deciduous

please give the type of tooth A?
    Answer is  valid              {ask what are valid answers - the
                                   response also given to invalid reply}
X is-a valid-answer if
        X member-of (incisor canine premolar molar)

please give the type of tooth A?
    Answer is  incisor

which incisor is tooth A?
    Answer is  corner

=== > (0.5 4.5)                          {the first answer to our query}
                  why                 {ask for explanation of answer}
I can show tooth (A) & A evidence-for (0.5 4.5)

how 2                               {ask for more details of 2nd condition}
I deduced A evidence-for (0.5 4.5)  from the rule
X evidence-for Y if
        X identified-as Z and
        Z present-from Y

I can show
 1 A identified-as (corner deciduous incisor)
 2 (corner deciduous incisor) present-from (0.5 4.5)

more                                        {ask for more answers}
is full-wear present on tooth A?  chain     {ask reason for question}

if      (X on A) appears-at 1 and
         X present-on A
 then    A evidence-for (1 inf)

 which is what you originally asked about

is full-wear present on tooth A?  yes
=== > (1 inf) more                          {ask for more answers}

is infundibulum present on tooth A?  yes
=== > (0 2) ok                              {end the session}
```

We thus know that the evidence of this tooth indicates an age range of between 0.5 and 4.5 years, an age greater than 1 and less than 2 years.

The system could infer from this that the horse was between 1 and two years old when it died. The system is in fact being extended to do this and also to avoid asking questions about galvayne's groove for example, which are obviously not relavent in this case.

Conclusions

This paper has illustrated the application of Expert systems techniques to one small area of archaeology. However we have only scratched the surface and there is enormous potential for the much wider use of such techniques by archaeologists. It is hoped that this potential will be realised particularly now that tools such as expert system shells like APES [3] are emerging from research into Intelligent Knowledge Based Systems (IKBS).

Acknowledgements

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References

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[3] Hammond P. APES - a user manual. Department of Computing report No 82/9, Imperial College, London SW7.