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"PANDORA" EKSPERTNI SISTEM ZA DATIRANJE ISKOPINA

ABSTRAKT

Datiranje predmeta informatičkim sredstvima, postalo je potreba koja se može rešiti samo kompleksnim ekspertnim sistemom. Veštačka inteligencija u službi arheologije pruža široke mogućnosti koje nisu ostvarive klasičnim arheološkim sistemima dokumentovanja i obrade. Pandora je za predmet obrade uzela žižke kao jedan od najraširenijih predmeta koji su dostupni u arheološkim zbirkama.

Ključne reči: ekspertni sistem, veštačka inteligencija, arheologija, informatika, datiranje, pandora, žižak.

UVOD

Namera ovog članka je da opiše ekspertni sistem PANDORA koji se koristi u arheološkim istraživanjima i da skrene pažnju (arheološke javnosti) na mogućnost šire primene veštačke inteligencije u okviru arheološke nauke.

Veštačka inteligencija je oblast koja se u okviru computer sciences intenzivno razvija od kasnih šezdesetih godina naovamo. Ona obuhvata skup raznovrsnih disciplina, kao što su pattern recognition (prepoznavanje oblika), neuronske mreže (neural networks), machine learning (mašinsko učenje), automated deduction (automatsko dokazivanje teorema) itd. Veštačka inteligencija je izvor mnogobrojnih kontraverzi, a literatura o njoj je izuzetno obimna. Detaljni prikazi mnogih oblasti veštačke inteligencije i spiskovi referenci dati su u [encikl. of ai].

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Ekspertni sistemi, najuspešniji i najkomercijalniji proizvod veštačke inteligencije, su programi koji manipulišu znanjem iz neke oblasti da bi na kvalitetan način odgovarali na pitanja koja uobičajeno rešavaju ljudi - eksperti. Primene ekspertnih sistema su česte u medicini, hemiji, vojnoj i naftnoj industriji. Međutim, retki su primeri ekspertnih sistema u društvenim naukama, pa i u arheologiji. Koliko nam je poznato, o ekspertnim sistemima u arheologiji retko je pisano, što ukazuje da bi ovoj temi trebalo posvetiti veću pažnju.

U daljem tekstu mi nećemo apstraktno razmatrati primenljivost metoda veštačke inteligencije u arheologiji, niti ćemo se preterano baviti tehničkim aspektima programa, već nam je namera da kroz nekoliko primera predstavimo konkretan ekspertni sistem PANDORA i iskustva do kojih smo došli u njegovom razvoju.

EKSPERTNI SISTEMI

Ekspertni sistemi se mogu, bez obzira na njihovu raznolikost, šematski prikazati kao na slici 1.

slika 1:
- baza ekspertskog znanja (knowledge base)
- inference engine (mehanizam izvođenja)
- user interface (unos znanja i upotreba es-a)
- deo za objašnjenja, učenje, korekcije

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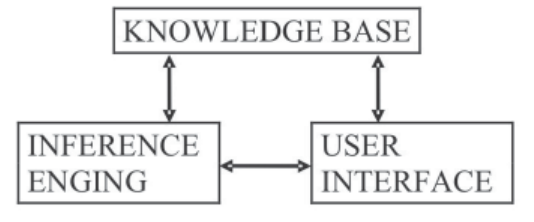
Osnovni delovi ekspertnog sistema su: baza znanja, mehanizam izvođenja i korisnički interfejs (user interface). Baza znanja za konkretan problem se formira intervjuisanjem čoveka eksperata, iz publikacija i postojećih konvencionalnih baza podataka (data base). Baza znanja sadrži formalizovano znanje i, delimično, intuiciju koju ekspert koristi u zaključivanju o određenom pitanju. Znanje se zapisuje i pamti u obliku pogodnom za obradu mehanizmom izvođenja kojim se vrši zaključivanje. Korisnički interfejs omogućava da se sa ekspertnim sistemom komunicira na jednostavan i pregledan način. Ovo se odnosi na postavljanje pitanja, davanje objašnjenja, prikazivanje slika itd. Ekspertni sistemi često sadrže i druge delove: za objašnjavanje, ispitivanje konzistentnosti znanja, za učenje itd. Posebno je značajno da ekspertni sistem može da objasni svoje postupke, odnosno kako je došao do zaključaka i zašto preduzima neko dejstvo. Ovo sa jedne strane može da korisnika ekspertnog sistema uveri u ispravnost donetog zaključka, a sa druge da ilustruje način rezonovanja eksperta čije se znanje koristi.



Slika 1. Šematski prikaz ekspetnih sistema

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U realizaciji PANDORA-e uglavnom je korišćena metodologija na kojoj je baziran jedan od najpopularnijih ekspertnih sistema MYCIN.

OSNOVI EKSPERTNOG SISTEMA PANDORA (PANDORA BASICS)

Prvo pitanje sa kojim smo se susreli pri razvoju ekspertnog sistema PANDORA odnosilo se na primenljivost veštačke inteligencije u arheologiji. Zbog toga je bilo potrebno izabrati jednu oblast arheološkog znanja i u okviru nje neposredno stići do prvih iskustava.

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Smatrali smo da treba poći od određenog arheološkog predmeta koji mora da ispunjava nekoliko uslova:

a) da hronološki obuhvata dovoljno dug period (najmanje period od pola milenijuma)

b) da je u nauci relativno stabilno određena njegova formalna klasifikacija

c) da pokriva širu teritoriju (bar jednog kontinenta)

d) da postoji prohodnost predmeta po teritorijalnoj osnovi (da se isti tipovi susreću na više mesta i da postoji njihova međusobna zavisnost u tipološkom i hronološkom smislu)

e) da postoje nepobitni dokazi o impotru određenog predmeta

f) da postoji dovoljan broj uzoraka (više hiljada) koji će biti predmet ES

h) poželjno je utvrditi i moguće pravce prodora i uticaja kao i transverzale mogućih komunikacija.

h) da predmeti imaju što precizniju hronološku odrednicu (što precizno datovanje u okviru hronološkog sloja, datovanje novcem itd.).

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Ubrzo se pokazalo da je arheološko znanje koje koristimo višeslojno. Osnovno, faktografsko znanje se zasniva na poznatim klasifikacijama lampi koje se vrše na osnovu tipoloških svojstava i načina izrade. Na osnovu toga se može zaključiti da određeni tip lampe pripada nekom hronološkom periodu. Međutim, ovo je tačno samo u izvesnoj meri, i zavisi od raznih faktora, kao što su: prostor sa kojeg lampe potiču, migracije pojedinih majstorskih radionica za izradu lampi itd. Upravo tu se nailazi na pravu intuiciju arheologa eksperta pri čemu se razmatraju mnogi dodatni faktori neophodni za datiranje. U daljem tekstu daćemo nekoliko primera koji se odnose na taj viši nivo arheološkog znanja.

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Sa stanovišta razvoja ekspertnog sistema značajno je da se pokazalo da je arheološko znanje pogodno za formalizaciju. Znanje se zapisuje i pamti u simboličkom obliku zvanom pravila (rules) čiji je opšti oblik:

if CONDITION (USLOV) then CONCLUSION.

PANDORA transformiše pravila u interni oblik koji ovde nije od posebnog značaja. U bazi znanja koja se odnosi na rimske lampe između ostalih se nalaze sledeća pravila:

if CONDITION (USLOV) then CONCLUSION.

PANDORA transformiše pravila u interni oblik koji ovde nije od posebnog značaja. U bazi znanja koja se odnosi na rimske lampe izme|u ostalih se nalaze sledeća pravila:

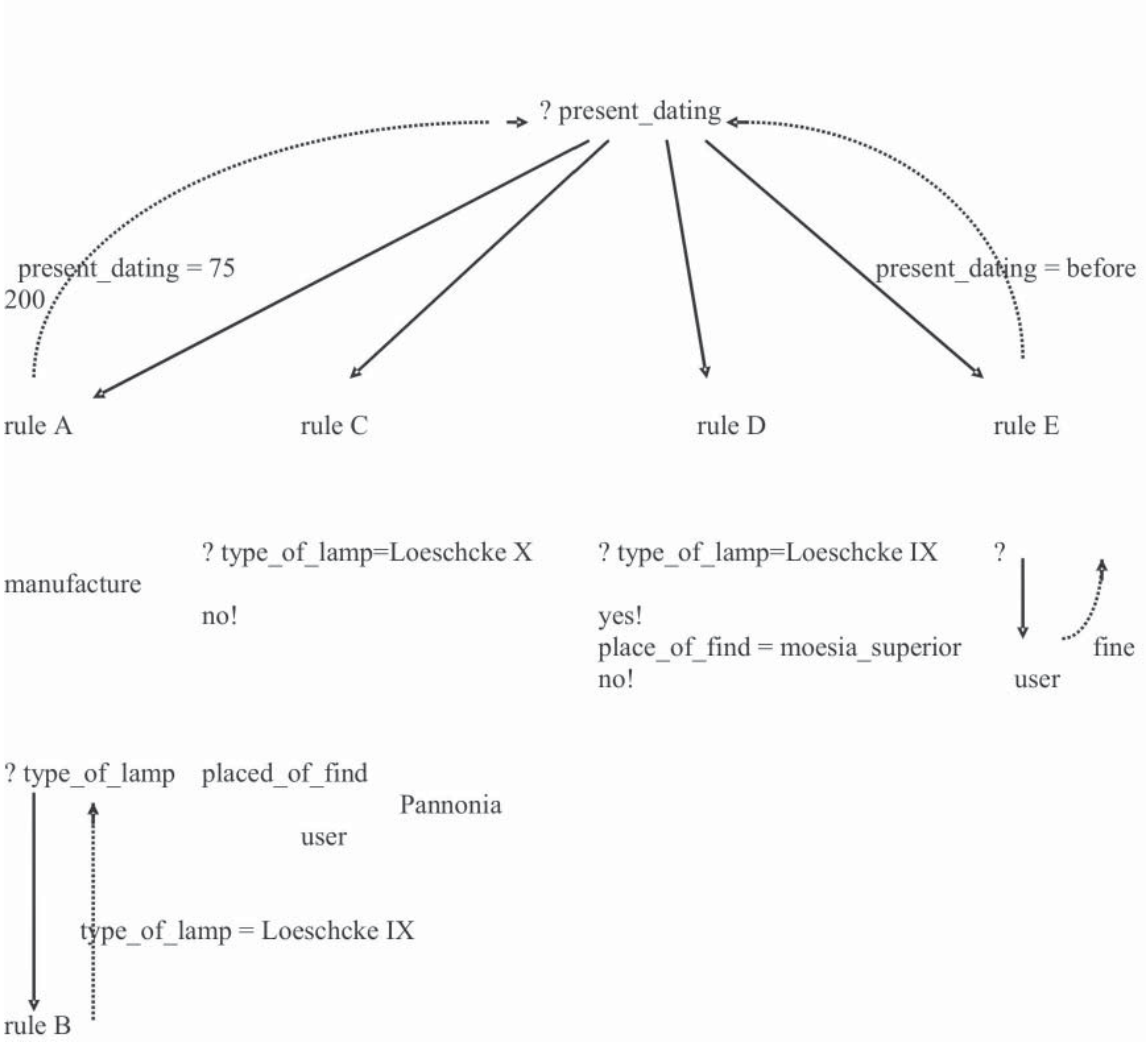
```
a::
if
   tip_lampe = loeschcke_IX  and mesto_nalaza = pannonia
then
   postojece_datovanje = 75.

b ::  if
   recepijent = kruskoliki and izduzenost_kljuna = nesto_izduzen
    and disk = obrubljen_prstenom and
     (kanal = siri or kanal = uzi or kanal = otvoren
    or kanal = zatvoren) and
    (otvor_za_ulje = centricno_postavljen or
      otvor_za_ulje = ekscentricno_postavljen) and
    kljun = zaobljen_na_vrhu
then
tip_lampe = loeschcke_IX.

c::
if
   tip_lampe = loeschcke_X and mesto_nalaza = moesia_superior
then
postojece_datovanje = 70.

d::
if
   tip_lampe = loeschcke_IX and mesto_nalaza = moesia_superior
then
postojece_datovanje = 30.

e::
if
   izrada=fina
then
```



slika 2 (inference tree)

postojece_datovanje=’verovatnije pre dvestote god.’.

U pravilu a se, ako je tip lampe loeschcke IX, a mesto nalaza pannonia, zaključuje da se prema postojećim saznanjima lampa datira oko 75. godine nove ere. Slično se i u pravilima c i d datiranje određuje na osnovu mesta nalaza lampe i njenog tipa. Pravilo b na osnovu vizuelnih karakteristike lampe, recimo da je recepijent kruškolik i kljun nešto izdužen itd, zaključuje da je tip lampe loeschcke IX. Pravilo e datovanje na osnovu postojećih saznanja određuje prema kvalitetu izrade lampe, pa ako je ona fina, lampa se smešta u period pre dvestote godine nove ere.

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Zbog broja i veličine pravila nije moguće u kratkom članku koristiti punu bazu podataka, pa ćemo postupak zaključivanja ilustrovati na ovim pravilima. Pri radu sa PANDORA-om korisnik postavlja pitanje u vezi perioda nastanka iskopine. Mehanizam izvođenja, kao na slici 2, pronalazi sva pravila koja u zaključku određuju vrednost perioda. To su pravila A, C, D i E. Mehanizam izvođenja sada ispituje da li su ispunjeni uslovi tih pravila, da bi na osnovu njihove tačnosti, odredio vrednost za entitet period. Ispitivanje uslova pravila A zahteva da se utvrdi koji je tip_lampe i mesto_nalaza. U određivanju vrednosti za tip_

lampe, na sličan način kao i za period, pronalaze se sva pravila koja u zaključku dodeljuju vrednost ovom entitetu. U ovoj skraćenoj bazi to je samo pravilo B, iako se u stvarnoj bazi znanja nalazi mnogo više takvih pravila. Postupak se ponavlja sa entitetima koji se nalaze u uslovu pravila B. Ako se za neki entitet vrednost ne određuje u zaključku ni jednog pravila, kako je ovde slučaj sa entitetima recepijent, izduzenost_kljuna, ... mehanizam izvođenja postavlja pitanje korisniku o njihovom obliku. Pretpostavimo da se na osnovu dobijenih odgovora zadovoljava uslov pravila B. Tada se entitetu tip_lampe dodeli vrednost loeschcke IX. Mehanizam izvođenja ponovo analizira pravilo A i traži vrednost za mesto_nalaza. Istim postupkom, ako bi entitet dobio vrednost pannonia, zaključilo bi se da je uslov pravila ispunjen i da je vrednost entiteta postojece_datovanje 75. U opštem slučaju slično bi se radilo i sa pravilima C i D, mada je u ovom konkretnom slučaju to nepotrebno, pošto tip_lampe i mesto_nalaza imaju jedinstvene vrednosti. Međutim, to nije slučaj i sa pravilom E. U njemu se vrednost entiteta postojece-datovanje određuje na osnovu kvaliteta izrade, pa ako je izrada fina zaključuje se da je iskopina nastala pre dvestote godine. Tako bi ekspertni sistem PANDORA, u ovom pojednostavljenom, ali ilustrativnom, slučaju odgovorio:

This is what is known about postojece_datovanje::

postojece_datovanje = verovatnije pre dvestote god. cf 100

Reasons:: e

postojece_datovanje = 75 cf 100

Reasons:: d

period = ... by rule A

period < ... by rule E

U tom trenutku korisnik može postaviti pitanje kako se došlo do zaključaka, kada bi se u odgovarajućoj formi ponovila istorija zaključivanja:

e => s

izrada => s / e

izrada => user

postojece_datovanje => e

d => s

tip_lampe => s / d

b => s

kljun => s / b

kljun => user

otvor_za_ulje => s / b

otvor_za_ulje => user

kanal => s / b

kanal => lookup

kanal => f / b

kanal => user

disk => s / b

disk => user

izduzenost_kljuna => s / b

izduzenost_kljuna => user

recepijent => s / b

recepijent => user

tip_lampe => b

mesto_nalaza => s / d

mesto_nalaza => lookup

postojece_datovanje => d

c => f

mesto_nalaza => f / c

mesto_nalaza => lookup

postojece_datovanje => c

a => f

mesto_nalaza => f / a

mesto_nalaza => user

postojece_datovanje => a

Takođe, u trenutku kada ekspertni sistem postavi pitanje korisniku o nekom entitetu, na primer o obliku kljuna, korisnik može postaviti pitanje zašto je taj podatak potreban, nakon čega bi dobio odgovor:

I am investigating tip_lampe

Your answer to this question will help me de-

termine
whether the following rule is applicable::
b::
if recepijent = kruskoliki
and izduzenost_kljuna = nesto_izduzen
and disk = obrubljen_prstenom
and kanal = siri
or kanal = uzi
or kanal = otvoren
or kanal = zatvoren
and otvor_za_ulje = centricno_postavljen
or otvor_za_ulje = ekscentricno_postavljen
and kljun = zaobljen_na_vrhu
then tip_lampe = loeschcke_IX
The current state of the agenda is::
Thing Rules yet to be tried
postojece_datovanje d e

Ove dve vrste objašnjenja PANDORA daje razmatranjem drveta izvođenje (inference tree) koje je prikazano slikom 2. Iz njega je moguće reprodukovati redosled ispitivanja pravila čime se opisuje istorija zaključivanja. Takođe, pravila koja se u drvetu nalaze neposredno ispod čvorova u kojima se korisniku postavlja neko pitanje objašnjavaju zašto je to pitanje postavljeno.

NAPREDNI ELEMENTI EKSPERTNOG SISTEMA PANDORA

Kao što je već sugerisano, datiranje iskopina, lampi, na osnovu njihovog tipa nije preterano inteligentan posao i može se efikasno realizovati pomoću kovencionalnih baza podataka. Međutim, svaki arheolog dobro zna, a svaki saradnik arheologa brzo shvati, da je zaključivanje koje izvode arheolozi mnogo složenije. Osnovni zadatak koji smo ispred sebe postavili u realizaciji PANDORA-e je bio da se formalizuje što više od intuicije arheologa kako bi program mogao bolje da rešava probleme. Pokazalo se da je to u znatnoj meri moguće. Navešćemo nekoliko primera pravila koja prevazilaze jednostavno datiranje na osnovu klasifikacije prema tipu lampe. Pomoću takvih pravila može se povećati sigurnost već postignutih odgovora, ali i postaviti sasvim nove hipoteze.

f::
if
tip_lampe = loeschcke_IX and
mesto=X and
prolog(dsetupn(Š(italia,30)Ć)) and
then
datum_prema_susedstvu=D.

g::
if
novac_u_sloju_nađen=da and datum_novca=X
then
datum_prema_novcu=X.
h::
if
poreklo_iz_prethodnih_perioda=da and datum_ziska_pretka=D
then
datum_prema_pretku > D.

U pravilu f se analizira distanca mesta nalaza lampe od centra proizvodnje i u obzir uzimaju trgovačke i društvene prilike vremena nastanka lampe. Najpre se pretpostavlja da su lampe čiji je tip loeschcke IX počele da se proizvode u Italiji, tridesete godine nove ere (prolog(dsetupn([(italia, 30)]))). Zatim se izračunava mera udaljenosti mesta nalaza lampe od Italije (prolog(distance(X,D))). Tu se pretpostavlja (arheološka intuicija) da se iz jedne u drugu njoj susednu provinciju koja je dalja od Italije, lampa prenosi nakon najviše 5 godina od osvajanja te dalje provincije. Na osnovu ovakvog postupka se pronalazi najkraći vremenski put od Italije do provincije u kojoj je lampa pronađena, na osnovu čega se procenjuje vreme nastanka lampe. Pravilo g zaključak daje na osnovu novca koji je eventualno pronađen u sloju u kom i lampa, dok pravilo h koristi sličnost pronađene lampe sa lampom nekog drugog već datiranog tipa.

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Na primer, PANDORA koristeći prvo od navedenih pravila postavlja hipotezu da se lampa tipa loeschcke IX može očekivati u provinciji Dakija već 111. godine (pošto se u susednoj Moesiji javlja, što je za dvadesetak godina ranije, nego što se smatra.

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Pravila koja se koriste u PANDORA-i su zapravo nešto složenija nego što je to do sada prikazano. Ona mogu sadržati i informacije o pouzdanosti znanja (certainty factor) koje je njima opisano. To treba da omogući zapisivanje onog dela znanja eksperta u kome se javljaju konstrukcije oblika 'ako je ..., onda je većinom ...' i slične koje su uobičajene u arheologiji, posebno s obzirom da su iskopine često oštećene, ili predstavljaju samo fragmente originalnih predmeta. Mehanizam izvođenja obezbeđuje kombinovanje faktora sigurnosti prilikom zaključivanja. Ako je uslov nekog pravila oblika A and B, tada je faktor sigurnosti tog uslova manji od faktora sigurnosti sa kojima su zaključeni A, odosno B. Ili, ako neko pravilo potvrdi već zaključenu vrednost entiteta, to povećava sigurnost zaključka. PANDORA će u odgovoru na postavljeno pitanje prikazati i faktor sigurnosti rezultata sugerišući time kolika mu je pouzdanost. Ako, tokom zaključivanja faktor sigurnosti padne ispod neke unapred definisane vrednosti, postupak se može prekinuti uz odgovarajuće objašnjenje. U vezi sa sigurnošću znanja u arheologiji je prisutan i problem da je veoma često istraživačima dostupan samo deo originalnog predmeta, dok, recimo, izgled nekih nedostajućih delova nije poznat. Sledeće pravilo ilustruje kako se u PANDORA-i postupa u takvim situacijama. Njime se zapisuje da ukoliko nije poznat oblik kljuna, zaključuje se da je tip lampe loeschcke IX, ali sa smanjenom sigurnošću koja sada iznosi 80 posto.

```
i::
if
   recepijent = kruskoliki
   and disk = obrubljen_prstenom and
      ( kanal = siri or kanal = uzi or kanal = otvoren
      or kanal = zatvoren) and
      (otvor_za_ulje = centricno_postavljen or
       otvor_za_ulje = ekscentricno_postavljen) and
      kljun = unknown
   then
   tip_lampe = loeschcke_IX cf 80.
```

PANDORA dopušta upotrebu multimedijalnih sredstava, poput slika, što smatramo originalnim doprinosom. Recimo, korisniku (user) se predočavaju digitalizovane fotografije kljunova raznih oblika, tako da on može vizuelno prepoznati i klasifikovati onaj koji je pronašao.

REZULTATI RADA EKSPERTNOG SISTEMA PANDORA

U ovom trenutku, ekspertni sistem PANDORA poseduje oko 600 pravila o rimskim lampama.[1] Kvalitet odgovora koji daje PANDORA, kada su joj dostupni relevantni podaci, je na nivou arheologa eksperta koji se bavi ovom oblašću. Istovremeno, PANDORA je u stanju i da postavlja, u odnosu na literaturu, samostalne hipoteze o datiranju iskopina. Na svakom koraku izvođenja, PANDORA na zahtev korisnika nudi objašnjenje u vezi istorije rada, odnosno razloga za neki postupak. Multimedijalne pogodnosti, prikazivanje slika, video i zvučnih zapisa, kao i svojevrsna baza podataka znatno brže dovode do relevantnih podataka, nego što je to slučaj sa klasičnim tekstom. Pored toga, nezavisnost baze znanja od mehanizma izvođenja dozvoljava da isti program radeći nad raznim podacima preuzima ulogu eksperata iz raznih oblasti. Sve ovo čini da je PANDORA pogodna i za uloge konsultanta istraživačima i kao edukativno sredstvo kojim se studentima ilustruje rad eksperata.

1. U toku je dalji razvoj ES PANDORA koji treba da sadrži preko 2.000 pravila.

* * *

Odgovori koje daje PANDORA su implicitno sadržani u znanju, odnosno pravilima u bazi znanja. U tom smislu, PANDORA ne može ponuditi ništa što joj na posredan način nije unapred ugrađeno. Ali, PANDORA sistematski provera mogućnosti i može doći do odgovora koje bi čovek previdео zbog velikog obima raspoloživog znanja. Na taj način PANDORA može davati odgovore koji do sada nisu ponuđeni u stručnoj literaturi.

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Kreiranje kvalitetnih baza znanja je najteži i najduži deo posla u izradi jednog ekspertnog sistema. Potrebno je pomiriti dva suprotstavljena zahteva: s jedne strane znanje mora biti konzistentna, dok sa druge mora sadržati što je više moguće podataka kako bi se precizno opisao problem. Ti podaci su po svojoj prirodi multidisciplinarni, pa je poželjno angažovanje eksperata iz raznih nauka, a ne samo arheologa. I izbor eksperata čije se znanje i iskustvo ugrađuje u bazu znanja može dovesti do raznih problema, na primer do neusaglašenosti po nekom pitanju. Međutim, tada je moguće pružati odgovore koji će u sebi sadržati informaciju o poreklu znanja, pa čak i bez predrasuda ponuditi više odgovora raznih, eventualno suprotstavljenih, eksperata. U svakom slučaju, nakon razvoja ekspertnog sistema na raspolaganju je moćno sredstvo za obuku i istraživanje sa kojim se može raditi vrlo brzo. Poređenja radi, ako se vreme školovanja i sticanja iskustva jednog arheologa meri godinama, ili čak decenijama, vreme kreiranja ekspertnog sistema izražava se mesecima, a startovanja programa sa raznim bazama znanja i dobijanja odgovora minutima, pri čemu je dobitak nesumnjiv.

* * *

Konačno, ali ne i najmanje važno, preispitivanje, formalizacija, kao i digitalizacija raspoloživog arheološkog znanja, koji se sprovode tokom razvoja ekspertnog sistema pružaju mogućnost iskoraka u standardizaciji znanja u smislu formata zapisa, usaglašenosti teorija, lakšeg otkrivanja nekonzistentnosti, šire dostupnosti znanja itd. Planovi vezani za razvoj PANDORA-e se, pored tehničkih unapređenja sistena, upravo odnose na postupno kreiranje baza znanja vezanih za pokrivanje naučnih oblasti koje predstavljaju specijalnost saradnika Arheološkog instituta, kao i lokaliteta na čijem istraživanju sarađuju.

* * *

O dometima veštačke inteligencije gotovo da je stalno otvorena rasprava između optimista i pesimista. Bez obzira na poziciju koja se zauzme u odnosu na mogućnosti veštačke inteligencije, sigurno je da ekspertni sistemi neće zameniti arheologe. To i nije njihova namena. Naprotiv, oni treba da omoguće kvalitetnije obučavanje i rad istraživačima. Kakvi su stvarne šanse za to i kuda zaista vodi razvoj i primena veštačke inteligencije? Pandora, ime kojim smo nazvali ekspertni sistem, simboliše s jedne strane nepresušnu ljudsku radoznalost, a sa druge sve dobro i zlo koje je izašlo iz krčaga, a pogotovo nadu koja je u njemu ostala.

Zahvaljujemo se preminulom akademiku Dragoslavu Srejoviću, koji nam je pružio značajnu moralnu podršku u radu.

PANDORA
Experts system for dating artifacts

Miomir Korać, Zoran Ognjanović, Filip Dugandžić

* * *

INTRODUCTION

The aim of this paper is to describe an expert system PANDORA used in archaeological explorations, and to call the attention (of archaeological public) to a possibility of broader application of artificial intelligence within the science of archaeology. A field related to artificial intelligence, within the framework of computer sciences, has been intensively developed since the late 1960s. It comprises a set of various disciplines, such as the pattern recognition, neural networks, machine learning, automated deduction, etc. Artificial intelligence is a source of numerous controversies, and the bibliography related to it is fairly broad. Various fields of artificial intelligence and reference lists are ordered in [encikl. of ai].

Expert systems, the most successful and most commercial products of artificial intelligence, are the programs that manipulate with data from particular field to deal with questions - usually solved by expert people - in the most accurate way. Applications of expert systems are frequent in medicine, chemistry, military and petrol industry. However, the examples of expert systems in social sciences, and hence in archaeology too, are rare. As far as we know, the expert systems in archaeology were noted only in, and this fact implies that a greater attention should be paid to that topic.

We are not going to discuss suitability of artificial intelligence methods further in this paper, nor we are going to deal with technical aspects of the program in greater extent. However, our intention is to represent actual expert system PANDORA through several examples, as well as the experiences acquired during its development.

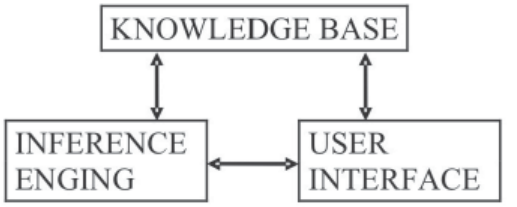

Figure 1. Schematical representation of expert system

EXPERT SYSTEMS

Notwithstanding their diversity, the expert systems could be schematically represented as in fig. 1.

- knowledge base
- inference engine
- user interface
- a part for explanations, learning, corrections

The basic parts of an expert system are: knowledge base, operation mechanism and user interface. Knowledge base that relates to a particular problem is formed by interviewing an expert person, as well as by data from publications and existing conventional data bases. Knowledge base consists of formalized knowledge, and partially, of intuition employed by an expert in his reasoning about particular question. Knowledge is recorded and memorized in a form that is suitable for inference engine which brings up the conclusion. User interface provides simple and accessible communication with an expert system. It deals with posing questions, providing explanations, picture representations, etc. Expert systems may often contain other parts: for explication, exploring the knowledge consistency, learning, etc. It is

especially significant that expert system should be capable to explain its procedure, i.e., the way it reached particular conclusion, and the cause of undertaking particular action. On the one hand, conclusions inferred by an expert system user could thus be confirmed, but on the other hand, a mode of reasoning of an expert whose knowledge is used could hence be illustrated.

Methodology based upon one of the most popular expert systems MYCIN, was used in realization of PANDORA expert system.

PANDORA BASICS

The first question posed during development of PANDORA expert system dealt with an adequacy of the application of artificial intelligence in archaeology. Therefore, it was necessary to select a particular field of archaeological knowledge and to gain initial experience within its framework directly.

We thought that one must start from a particular archaeological object that must conform to several conditions:

a) period it encompasses has to be adequately long (at least a period of half millennium).

b) relatively firm establishment of its formal classification in science.

c) its territorial distribution has to be broad (at least on continental scale)

d) its territorial availability has to exist (that same types are present on a number of places, and they have to be interdependent both chronologically and typologically)

e) import of certain object has to be positively confirmed.

f) the sample of ES has to be adequate (several thousand)

g) it is desirable to establish possible directions of advancement and influence, as well as the routes of possible communication

h) chronological determination of objects should be as accurate as possible (precise dating witin chronological layer, dating by coinage, etc.

Concerning the noted remarks, the Classical period was chosen, i.e., the Roman imperial period. We thought that this period was suitable for two reasons. Firstly, the Roman state was centralized with strict administrative, formal norms. Secondly, the history of Roman Empire is rather accurately determined according to periods of government of each emperor. A chronology like this one is suitable for testing the results of ES, at least in the initial stage of the expert system construction. A particular kind of artifact has then been selected - lamps (lanterns). Finally, […[, […[, served as the source of knowledge, along with rich finds from the territory of Moesia Superior, from excavations of Viminacium. More than 13 000 graves were uncovered during previous fifteen years, with 4 000 lamps dating from I to VI century. The noted lamps were thoroughly studied in Ph. D. thesis by M. Korac […\

Almost immediately it appeared that the archaeological knowledge used is multifarious. The fundamental, factographic knowledge is based upon familiar classifications of lamps created upon typological traits and mode of their manufacture. Attribution of particular lamp to certain chronological period has usually been inferred upon these data. However, it could be accurate only to a certain extent, as it depended on various factors such as: area of the lamp's origin, migration of particular lamp workshops, etc. Genuine intuition of an archaeologist expert takes place exactly at the noted point, and it takes into account various additional factors that are indispensable for datation. Further in this text we shall present several examples relating to the noted higher level of archaeological knowledge.

From the standpoint of expert system, a confirmation that archaeological knowledge was suitable for formalization has been significant. The knowledge is recorded and memorized in a symbolic form called the rules, having a general form as:

if CONDITION then CONCLUSION

PANDORA transforms the rules into an internal form that is not particularly significant here.

Within the knowledge base dealing with Roman lamps, the following rules could be singled out:

a::
if
type_of_lamp= loeschcke_IX and place_of_ find = pannonia
then
present_dating = 75

b::
if
body = pear-shaped and nozzle_extension = fairly_ elongated
and disk = bordered_ by_ring and (channel = wide or channel = narrow or channel = open or channel = closed) and (filling-hole = placed_in _center or filling-hole = placed_off-center) and nozzle = rounded_on_top
then
type_of_lamp = loeschcke_IX

c::
if
type_of_lamp= loeschcke_X and place_of_ find = moesia_superior
then
present_dating = 70.

d::
if
type_of_lamp= loeschcke_IX and place_of_ find = moesia superior
then
present_dating = 30.
e::
if
manufacture = fine

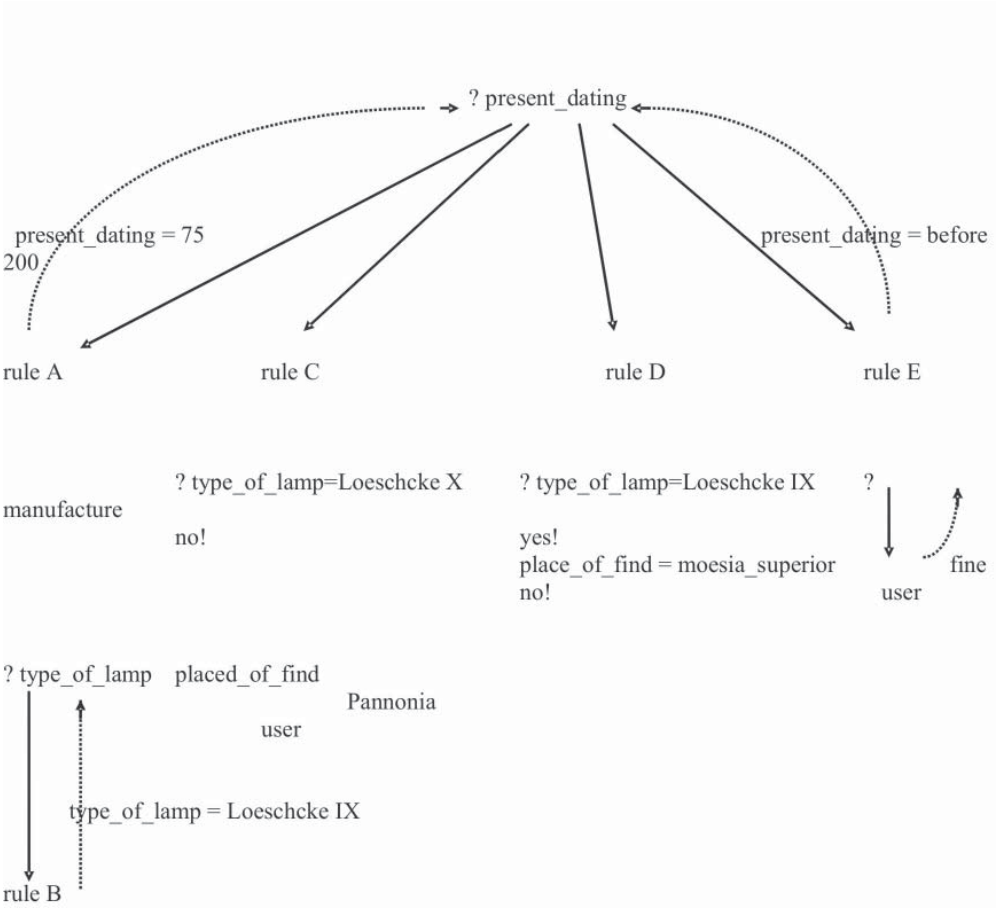

Fig. 2 Inference tree

then
present_dating = ‘probably_before_200’.

As a rule, if the type of lamp was loeschcke IX, and the place of find Pannonia, it is inferred according to existing evidence, that it could be dated cca. 75 A.D. In the same way, in rules c and d, datation is determined according to the lamp’s place of find and its type. By rule b, based upon lamp traits observed visually, i.e., pear-shaped body and elongated nozzle, etc., it is inferred that the type of lamp was loeschcke IX. Rule e determines the age according to lamp’s quality of manufacture, based upon the existing knowledge. Therefore, if its quality was fine then the lamp is placed into a period earlier than 200 A.D.

The number and quantity of rules do not permit presentation of entire data base in this short paper, hence the inference procedure will be illustrated by the above noted rules. While working in PANDORA, the user asks a question related to the period of production of certain artifact. Inference engine, as in fig. 2, identifies all rules that determine age values in their conclusion. These are rules A, C, D, and E. Inference engine then examines if all conditions for these rules were fulfilled, and depending on their accuracy, it determines some value to the age entity. Examination of conditions in rule A demands determination of type_of_lamp and place_of_find. In determination of the type_of_lamp, similarly as it was done for the age, all rules that determine value to the noted entity are identified. It is only rule B in this shortened base, although in the actual knowledge base there are many more rules of that kind. The procedure is repeated with entities that appeared in conditions for rule B. If the value of some entity is not determined by conclusion of any one rule, as it is here the case with entities such as body, nozzle_extension ... inference engine poses a question to the user about their shape. Let us assume that the answers obtained fulfill a condition of rule B. The value loeschcke IX is then assigned to type_of_lamp entity. Inference engine analyzes again the rule A, and demands a value for place_of_find. By the same procedure, if an entity was assigned by the value pannonia, it could be inferred that the condition for the rule was fulfilled and that the value of present_dating entity was 75. Generally, a similar procedure would be applied to rules C and D, although in the above noted case it was not necessary, because type_of_lamp and place_of_find have the same values. However, it is not the case with rule E. Present_dating value is determined on the basis of the quality of manufacture, and if manufacture was fine it is inferred that the find dates back earlier than 200 A.D. In this simplified, but illustrative case, the expert system PANDORA would answer in the following way:

This is what is known about present_dating::
present_dating = probably before 200 cf 100
Reasons:: e
present_dating = 75 cf 100
Reasons d::
period = by rule A
period < ... by rule E

At this moment, the user could ask about the way it was inferred, and the history of inference would repeat itself in a corresponding form:

e = > s
manufacture => s/e
manufacture => user
present_dating =>e
d=> s
type_of_lamp => s/d
b=> s
nozzle = s/b
nozzle => user
filling-hole => s/b
filling-hole => user
channel => s/b
channel => lookup
channel => f/b
channel => user
disk => s/b
disk => user

nozzle_ extension => s/b
nozzle_extension => user
body => s/b
body => user
type_of_lamp = > b
place_of_find => s/d
place_of_find => lookup
present_dating => d
c => f
place_of_find = f/c
place_of_find => lookup
present_dating =>c
a =>f
place_of_find => f/a
place_of_find => user
present_dating => a

Also, in the moment when expert system asks the user about particular entity, i.e., about the shape of nozzle, the user my ask why this element was needed, and would subsequently receive an answer.

I am investigating type_of_lamp

Your answer to this question will help me determine whether the following rule is applicable::

b::
if body=pear-shaped
and nozzle_extension = elongated
and disk + bordered_by_ring
and channel = wide
or channel = narrow
or channel = open
or channel = closed
and filling-hole = placed_in_center
or filling-hole = placed_off_center
and nozzle = rounded_on_top
then type_of_lamp = loeschcke_IX
The current state of the agenda is::
Thing
Rules to be tried
present_dating d e

PANDORA obtains the noted two kinds of explanation by examination of the inference tree shown in fig. 2. Thus, it is possible to reproduce a sequence of the examination of rules, i.e., the history of inference is hence described. Also the rules, which are located in the tree just below the labels in which the user is asked to answer a question, explain why the particular question was posed.

PROGRESSIVE ELEMENTS IN ES PANDORA

As it was already suggested, dating of artifacts, the lamps, based upon their shape is not exceedingly intelligent task and could be efficiently realized by conventional data bases. However, as each archaeologist perfectly knows, and every collaborator of archaeologists quickly finds out, the inferences made by archaeologists are considerably more complex. The main task we had in mind in realization of PANDORA was to formalize the intuition of archaeologist as much as it was possible, so that the program could solve problems in a better way. It appeared that it was possible up to a considerable extent. We shall note several examples of rules that exceed the simple dating based on classification according to the type of lamp. With an aid of such rules, a certitude of already obtained answers could be increased, but also, new hypotheses could be posed.

F::
if
type_of_lamp = loeschcke _IX and
place=X and
prologue(dsetupn([(italia,30)])) and
then
date_regarding_neighbourhood = D.
g::
if
coin_in_layer_found=yes and date_of_ coin=X

then
date_regarding_coin=X

h::
if
origin_in_previous_periods=yes and date_of_prototype_lamp=D
then
date_regarding_prototype> D.

Rule f analyzes a distance of the lamp's place of find from the center of its production taking into account social and trading circumstances at the time of lamp's creation. Primarily it is assumed that lamps of loeschcke IX type were initially manufactured in Italy, in 30 A.D. (prologue(dsetupn([(italia,30)]))). Then the value of distance between lamp's place of find and Italy is calculated (prolog(distance(X,D))). Then it is assumed (intuition of archaeologist) that the lamp has been translocated from one province to another neighbouring province (still further from Italy) at the most within 5 years after the conquest of a distant province concerned. Considering the noted procedure, the shortest elapse of time is then calculated for translocation of the lamp from Italy to the province in which it was found, and the time of lamp's manufacture is then estimated. Rule g offers a conclusion based upon the coinage that was eventually found in the same layer as the lamp. Rule g, however, reaches the same goal through a similarity between the lamp found and a lamp of some other type that has already been dated.

For instance, PANDORA, if the first of the above noted rules was applied, may set a hypothesis that the lamp of loeschcke IX type could be expected in Dacia already in 111 A.D. i.e., twenty years earlier than it was previously thought.

The rules used in PANDORA are however more complex than the above noted presentation. They also may contain information on certainty factor regarding the knowledge described. It has to enable recording those parts of expert's knowledge in which constructions appear in the form "if so...., than overwhelms...." and the like, being a common place in archaeology due to a fact that finds are often damaged, or represent just the parts of original objects. Inference engine ensures participation of certainty factor in the course of reasoning. If the condition of a rule has A and B shape, than the certainty factor of the noted condition is lesser than certainty factor employed in conclusion of A, i.e., B. Or, if particular rule confirms the already determined value of entity, a certainty of conclusion will thus be increased. In its answer to the question posed, PANDORA will display certainty factor of the results obtained, at the same time suggesting their plausibility. If, in the course of reasoning, certainty factor falls below certain previously defined value, the procedure may be interrupted, with corresponding explanation. Concerning the certainty of knowledge, an additional problem appears in archaeology as it often happens that only a part of original object is available, and the looks of missing parts is unknown. The next rule illustrates how PANDORA operates in a situation like the noted one. It registers that if nozzle shape was unknown, it may be concluded that the lamp is of loeschcke IX type, but with certainty now decreased down to 80%.

I::
if
body = pear-shaped
and disk = bordered_by_ring and
(channel = wide or channel = narrow or channel = open or channel = closed) and (filling-hole = placed_in_center or filling-hole = placed_off_center) and nozzle = unknown then type_of_lamp = loeschcke_IX cf 80.

PANDORA provides the use of multimedial devices, i.e., pictures, and we assume it to be an original contribution. For instance, digitized photographs of various nozzles are shown, so that the user may recognize them visually and classify his finds.

RESULTS OF WORK OF ES PANDORA

The expert system PANDORA currently contains about 600 rules concerning the Roman lamps.[1] The quality of PANDORA's answer, if all relevant data were available, reaches a level of an expert archaeologist engaged in this field. At the same time, related to publications, PANDORA is able to set independent hypotheses about the age of artifacts. At each step of the procedure, if the user demands it, PANDORA may explain the history of operation, i.e., the cause for any one step made. Relevant data are thus reached much faster by multimedial utilities, representation of pictures, video and sound recordings, as well as a specific data base, than by the conventional text. In addition, independence of the knowledge base from inference engine allows an operation of the same program on various data, that is, it may play the role of experts from various disciplines. All the noted facts imply that PANDORA is suitable to be a consultant of explorers, as well as an educational means by which an expert work could be represented to students.

The answers offered by PANDORA are implicitly contained in the knowledge, i.e., rules in the knowledge base. In view of that fact, PANDORA can offer nothing but what was previously included into it. However, PANDORA systematically tests all possibilities and may reach an answer that could have been overlooked by a human because of the large amount of available knowledge. In this way, PANDORA may offer the answers that were not previously suggested in scholarly publications.

Creating knowledge bases of good quality represents the hardest and longest part in the expert system formation. It is necessary to harmonize two opposed demands: on the one hand the knowledge has to be consistent, and on the other it has to contain as much data as possible in order to define the problem precisely. The data concerned are multidisciplinary, and thus it is desirable to engage experts from various sciences, not only the archaeologists. The choice of experts whose knowledge and experience are included into knowledge base may lead to various problems, that is, if there was a disagreement about certain question. However, in that case, it is possible to provide answers which will contain information about the source of knowledge, and unbiasedly offer several answers of different, eventually opposed, experts. In any event, development of the expert system provides a powerful and fast means for training and exploration. For instance, if the time of training and experience acquirement for an archaeologist was measured by years, or even decades, the time of the expert system creation would be measured by months, and starting the programs with various knowledge bases and obtaining relevant answers - by minutes, hence its advantage is doubtless.

Last, but not least, the study, formalization, as well as digitizing of available archaeological knowledge, which have taken place during creation of expert system, provide a possibility of improving the knowledge standardization, as regards the record formatting, correspondence of theories, easier detection of inconsistencies, broader availability of knowledge, etc. Along with technical improvement of the system, the plans related to development of PANDORA are in fact concentrating around gradual creation of knowledge bases aiming to cover scientific fields which represent specialties of the collaborators of the Institute of Archaeology, as well as the sites they are studying.

An argument between optimists and pessimists is still open as concerns the scope of artificial intelligence. Notwithstanding a standpoint taken in view of the possibilities of artificial intelligence, it is certain that expert systems will not replace the archaeologists. And that was not their aim either. On the contrary, they have to provide a better quality of researcher's training and work. What

1. a work in further development of ES PANDORA, which will contain more than 2000 rules, is in course.

are the actual prospects for this aim and where does a development and application of artificial intelligence leads to? Pandora, a name given to our expert system symbolizes incessant human curiosity, but on the other hand, it symbolizes all good and evil released from the box, but above all a hope that have remained in it.

We wish to acknowledge a significant moral support to our work volunteered by the late academician Dragoslav Srejovic.

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