The Development of a Knowledge-Based Expert System for Analysis of Drainage Patterns*

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ABSTRACT: Drainage patterns can be a valuable indicator of the general characteristics of soil and rock in a given area. To facilitate the use of drainage pattern information in scientific experiments or engineering design, it is necessary to develop an expert system that could assist in determination of drainage pattern types. Such an approach to drainage pattern analysis has been described by Argialas *et al.* (1988) and is used here.

In this paper, the drainage pattern parameters and production rules were grouped in a root frame. The knowledge base was implemented using the Personal Consultant Plus expert system shell. A major advantage of this approach is the expert system has both development and consultation interface activities. The development activity was employed to construct the knowledge base while the consultation activity was intended to assist the end user. The example presented here demonstrates how the highly interactive and user friendly system shell can facilitate analysis of a given set of parameters and rules, and allow the user to determine the drainage pattern type.

INTRODUCTION

DRAINAGE PATTERNS result from various conditions of soil and rock topography, porosity, permeability, geologic structure, and chemical composition. The type of drainage pattern and its density can infer the presence and characteristics of the above features. Hence, it is useful to identify patterns from images, for engineering and scientific purposes (Way, 1978; Mintzer, 1983; Lyon, 1987).

Methods to facilitate the use of drainage pattern analysis through application of expert system shells remain to be developed. Here, we attempted to develop a preliminary system using an expert system shell, with the goal of helping users determine types of drainage patterns from given sets of information.

A comprehensive study of more than 30 patterns was earlier performed by Parvis (1950) and by Howard (1967). These efforts provided source materials and established characteristics to be incorporated in the description of patterns. The production rules developed for this experiment were based on a study performed by Argialas (1985). His research detailed the characteristic parameters and rules of drainage patterns. He employed these characteristics and relationships and classified eight drainage patterns commonly encountered by experts when assessing satellite image data. They are the dendritic, pinnate, parallel, trellis, rectangular, angular, radial, and annular drainage patterns. Further details as to how the parameter values were obtained, how the parameters were calculated, and how variability issues related to parameters of each pattern can be found in Argialas's papers (e.g., Argialas *et al.*, 1988) or dissertation (Argialas, 1985).

THE EXPERT SYSTEM SHELL

The expert system shell we employed was the Personal Consultant Plus version 4.0 (PC Plus). The system runs on IBM-compatible personal computers with DOS version 2.10 or higher. Memory requirements are at least 640K bytes of basic memory, plus 0.5 megabytes of extended memory. Our system currently runs with 40 megabytes of storage memory.

PC Plus is a highly interactive, functional tool for development of an expert system environment. It consists of two basic parts, the knowledge base and the inference mechanism. The knowledge base includes facts, rules relating the facts, and heuristic rules based on experience. The inference mechanism performs the inference procedure.

Other significant features of this expert system are its highly interactive environment for development and testing. The shell facilitates repetitive evaluations of patterns, and is more capable than older, structured command languages used in previous approaches. The system also provides access to external packages, graphic display capabilities, and a window-oriented interactive mode. These capabilities allow extensive on-line help, and communications that are so important in contemporary applications.

We developed the knowledge base through the construction of production rules. These rules were written in a language called Abbreviated Rule Language (ARL). ARL is a very capable language, and the meaning of commands can be translated into the English language for easier understanding of code and user prompts.

Parameters used for the production rules in the knowledge base were defined with ARL. These production rules and parameters were grouped in a frame, which formed the basis of the system.

There are two important activities involved in using the system. They include development of a knowledge base, and consultation interface with end user.

KNOWLEDGE BASE DEVELOPMENT

For the purpose of this study, a root frame called DRAINAGE was constructed. Several properties in this root frame were important, including DRAINAGE-PARMS (Parameters for Drainage Root Frame) and DRAINAGE-RULES (Drainage Production Rules). The DRAINAGE-PARMS was created to contain the parameters that form input to the rules. These parameters were based on drainage pattern characteristics. Examples of these parameters

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are TSHAPE (shape of trunk) and RJAW (ranked junction angle for the whole pattern). The other parameters are presented in Table 1.

Each drainage parameter has its own properties that are important for use in the consultation activity. The EXPECT property is required so that the end user can select the value of the parameter. For example, the value for TSHAPE is "straight" or "circular" while the value for BRTYPE is "onesided" or "twosided."

Another important property for the end user is the HELP function, which provides descriptions for each parameter. An example of invoking the HELP command for RJAW in the consultation mode is shown in Figure 1.

DRAINAGE-RULES contains 15 IF-THEN production rules based on Argialas' work (Argialas, 1985; Argialas *et al.*, 1988). The IF statement is commonly called the "antecedent," while the THEN statement is referred to as the "consequent." As mentioned before, the rules are written in ARL and can be translated into English. Figures 2 and 3 present examples of the rules in English.

The parameters and production rules presented in Figures 1, 2, and 3 are used in the consultation mode. The combination of ARL language capabilities and detailed visual explanations in menu form greatly facilitate these activities. In particular, training can be advanced by entering consultation mode as demonstrated in the following section.

TABLE 1. PARAMETERS FOR DESCRIPTION OF DRAINAGE PATTERNS (AFTER ARGIALAS ET AL., 1988). THE DESCRIPTIONS ARE ORDERED TOP-TO-BOTTOM FROM GENERAL CHARACTERISTICS TO THE MORE DETAILED OR SUBTLE CHARACTERISTICS THAT DESCRIBE DRAINAGE PATTERNS.

PARAMETER	DESCRIPTION
BLAZDIF	Azimuthal difference between branches and leaves
BRELON	Branch elongation
BRTYPE	Type of branching
BSHAPE	Branch shape
MABL	Mean junction angle between the branches and leaves
MALL	Mean junction angle among leaves
MAOB	Mean intermediate angle on the branches
MAOL	Mean intermediate angle on the leaves
MAOT	Mean intermediate angle on the trunk
MATB	Mean junction angle between the trunk and the branches
RANMT	Ranked angle with vertex on the center of gravity of the nodes and sides diverging to the mouth of the pattern and to its most distant node
RBRBL	Ranked bifurcation ratio between branches and leaves
RJAW	Ranked junction angle
TSHAPE	Shape of the trunk
UNLEAF	Uniformity of leaves

```
REMOTE-SENSING

Please provide the value of RJAW

ACUTE:  (MJAW < 70)          Help:
                             RJAW, the ranked junction angles for the whole
SACUTE: (MJAW < 40           pattern, is a geometric attribute developed to
        and ISDJAW < 15)     express the overall junction angle values. It
                             does not express the angularity of the various
RIGHT: (70 < MJAW < 130)     line segments, since it does not involve the
                             intermediate angles.
  ACUTE
  SACUTE                     MJAW is the mean junction angle of the whole
  RIGHT                      pattern.
                             ISDJAW is the standard deviation of the junction
                             angles of the junction angles of the whole
                             pattern.
                             ** End - press ENTER to continue.

 1. Use arrow key or first letter of item to position the cursor.
 2. press ENTER to continue.
```

FIG. 1. Display of an example of invoking the HELP command for RJAW in the consultation mode.

CONSULTING THE EXPERT SYSTEM

To employ the system, users need only to make a selection among answers provided on the screen. If a person were not familiar with the terms used in determining the drainage pattern, he or she can access HELP functions through the window-oriented, interactive, consultation mode. One question on the first screen in this mode will prompt display of the drainage pattern types that are addressed by this system (Figure 4).

The screens in Figures 5 through 21 show an example of a step-by-step consultation procedure used to reach a final conclusion as to drainage pattern type. Figures present the individual steps in the procedure, and do so in a self-explanatory manner.

```
REMOTE-SENSING

Rule:3
  IF   :: RANMT = LARGE AND TSHAPE = STRAIGHT AND RJAW != RIGHT AND
          RBRBL = LARGE AND BRELON != SHORT AND BRTYPE = TWOSIDED
  THEN :: PATTERN = "MORE LIKELY PINNATE"
Rule translation:

If    1) The ranked angle between the mouth of the farthest away node
         is LARGE, and
      2) The shape of the trunk is STRAIGHT, and
      3) The ranked junction angle is not RIGHT, and
      4) The ranked bifurcation ratio between branches and leaves is
         LARGE, and
      5) The branch elongation is not SHORT, and
      6) The branching type is TWOSIDED,
Then it is definite (100%) that the type of drainage pattern is MORE
LIKELY PINNATE.

** End - press ENTER to continue.

Display the English translation of the rule
```

FIG. 2. Display of an example of the rule in English.

```
REMOTE-SENSING

Rule:7
  IF   :: RANMT = LARGE AND TSHAPE = STRAIGHT AND RJAW = RIGHT AND
          RBRBL != SMALL AND BRELON != SHORT AND UNLEAF = UNIFORM
  THEN :: PATTERN = "MORE LIKELY TRELLIS"
Rule translation:

If    1) The ranked angle between the mouth of the farthest away node
         is LARGE, and
      2) The shape of the trunk is STRAIGHT, and
      3) The ranked junction angle is RIGHT, and
      4) The ranked bifurcation ratio between branches and leaves is
         not SMALL, and
      5) The branch elongation is not SHORT, and
      6) Uniformity of drainage pattern leaves is UNIFORM,
Then it is definite (100%) that the type of drainage pattern is MORE
LIKELY TRELLIS.

** End - press ENTER to continue.

Display the English translation of the rule
```

FIG. 3. Display of an example of the rule in English.

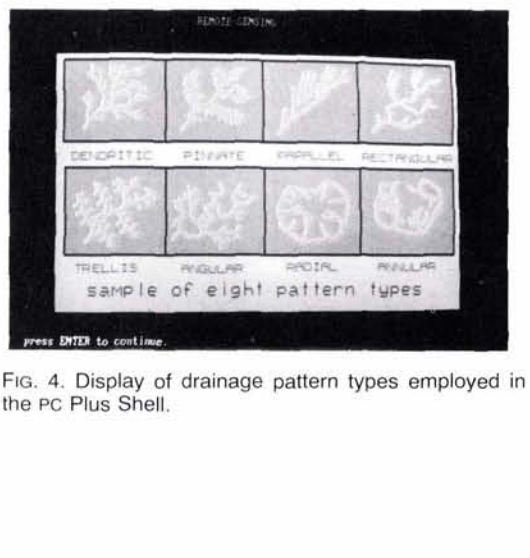

FIG. 4. Display of drainage pattern types employed in the PC Plus Shell.

REMOTE-SENSING

```
Please provide the value of BLAZDIF
  acute : (AZDIF < 68)
  right : (AZDIF > 68)

  ACUTE
  RIGHT

 1. Use arrow key or first letter of item to position the cursor.
 2. press ENTER to continue.
```

FIG. 5. Display of consultation screen for parameter BLAZDIF, azimuthal difference between branches and leaves.

REMOTE-SENSING

```
Please provide the value of BRELON
   SHORT  : (RMLRBL < 4.0)
   MEDIUM : (3.5 < RMLRBL < 4.8)
   LONG   : (4.8 < RMLRBL)

   SHORT
   MEDIUM
   LONG

 1. Use arrow key or first letter of item to position the cursor.
 2. press ENTER to continue.
```

FIG. 6. Display of consultation screen for parameter BRELON, branch elongation.

REMOTE-SENSING

```
Please provide the value of BRTYPE
   ONESIDED : (if KLEFT or KRIGHT equals 0)
   TWOSIDED : (if both KLEFT and KRIGHT are not 0)

   ONESIDED
   TWOSIDED

 1. Use arrow key or first letter of item to position the cursor.
 2. press ENTER to continue.
```

FIG. 7. Display of consultation screen for parameter BRTYPE, type of branching.

REMOTE-SENSING

```
Please provide the value of BSHAPE
   STRAIGHT : (STRBR < 1.1)
   BEND     : (1.1 < STRBR)

   STRAIGHT
   BEND

 1. Use arrow key or first letter of item to position the cursor.
 2. press ENTER to continue.
```

FIG. 8. Display of consultation screen for parameter BSHAPE, branch shape.

REMOTE-SENSING

```
Please provide the value of MABL
   ACUTE  : (MA12 < 70 AND SD12 < 37)
   OBTUSE : (120 < MA12 < 180 AND SD12 < 37)
   RIGHT  : (70  < MA12 < 120 AND SD12 < 37)

   ACUTE
   OBTUSE
   RIGHT

 1. Use arrow key or first letter of item to position the cursor.
 2. press ENTER to continue.
```

FIG. 9. Display of consultation screen for parameter MABL, mean junction angle between the branches and leaves.

REMOTE-SENSING

```
Please provide the value of MALL
   ACUTE  : (MA11 < 70 AND SD11 < 37)
   OBTUSE : (120 < MA11 < 180 AND SD11 < 37)
   RIGHT  : (70  < MA11 < 120 AND SD11 < 37)

   ACUTE
   OBTUSE
   RIGHT

 1. Use arrow key or first letter of item to position the cursor.
 2. press ENTER to continue.
```

FIG. 10. Display of consultation screen for parameter MALL, mean junction angle among leaves.

REMOTE-SENSING

```
Please provide the value of MAOB
   ACTUE  : (MA2 < 70 AND SD2 < 37)
   OBTUSE : (120 < MA2 < 180 AND SD2 < 37)
   RIGHT  : (70  < MA2 < 120 AND SD2 < 37)

   ACUTE
   OBTUSE
   RIGHT

 1. Use arrow key or first letter of item to position the cursor.
 2. press ENTER to continue.
```

FIG. 11. Display of consultation screen for parameter MAOB, mean intermediate angle on the branches.

Upon reviewing the figures, note that the underlined answer in Figure 21 was the choice made by the user with the assistance of the shell. The HELP property of the system allowed the user to access explanations and the graphical description of the pattern. Ultimately, use of the expert system shell program allowed identification of a drainage pattern that is a somewhat subtle version of the dendritic, the rectangular pattern. It is doubtful that a neophyte user would distinguish the difference between an angular, dendritic, and rectangular pattern without the "experience" stored in the expert system shell. Hence, this is a good example of how and when such an expert could be valuable in identifying drainage pattern types.

```
REMOTE-SENSING

Please provide the value of MAOL
   ACUTE  : (MA1 < 70 AND SD1 < 37)
   OBTUSE : (120 < MA1 < 180 AND SD1 < 37)
   RIGHT  : (70  < MA1 < 120 AND SD1 < 37)

   ACUTE
   OBTUSE
   RIGHT




  1. Use arrow key or first letter of item to position the cursor.
  2. press ENTER to continue.
```

FIG. 12. Display of consultation screen for parameter MAOL, mean intermediate angle on the leaves.

```
REMOTE-SENSING

Please provide the value of MAOT
   ACUTE  : (MA3 < 70 AND SD3 < 37)
   OBTUSE : (120 < MA3 < 180 AND SD3 < 37)
   RIGHT  : (70  < MA3 < 120 AND SD3 < 37)

   ACUTE
   OBTUSE
   RIGHT




  1. Use arrow key or first letter of item to position the cursor.
  2. press ENTER to continue.
```

FIG. 13. Display of consultation screen for parameter MAOT, mean intermediate angle on the trunk.

```
REMOTE-SENSING

Please provide the value of MATB
   ACUTE  : (MA23 < 70 and SD23 < 37)
   OBTUSE : (120 < MA23 < 180 and SD23 < 37)
   RIGHT  : (70  < MA23 < 120 and SD23 < 67)

   ACUTE
   OBTUSE
   RIGHT




  1. Use arrow key or first letter of item to position the cursor.
  2. press ENTER to continue.
```

FIG. 14. Display of consultation screen for parameter MATB, mean junction angle between the trunk and the branches.

```
REMOTE-SENSING

Please provide the value of RANMT
   SMALL : (ANGLMT < 105)
   LARGE : (105 < ANGLMT)

   SMALL
   LARGE




  1. Use arrow key or first letter of item to position the cursor.
  2. press ENTER to continue.
```

FIG. 15. Display of consultation screen for parameter RANMT, ranked angle with vertex on the center of gravity of the nodes and sides diverging to the mouth of the pattern and to its most distant node.

```
REMOTE-SENSING

Please provide the value of RBRBL
   SMALL  : (BR21 < 3.2)
   MEDIUM : (3.2 < BR21 < 4.0)
   LARGE  : (4.0 < BR21)

   SMALL
   MEDIUM
   LARGE




  1. Use arrow key or first letter of item to position the cursor.
  2. press ENTER to continue.
```

FIG. 16. Display of consultation screen for parameter RBRBL, ranked bifurcation ratio between branches and leaves.

```
REMOTE-SENSING

Please provide the value of RJAW

ACUTE:  (MJAW < 70)

SACUTE: (MJAW < 40
        and ISDJAW < 15)

RIGHT: (70 < MJAW < 130)

   ACUTE
   SACUTE
   RIGHT



  1. Use arrow key or first letter of item to position the cursor.
  2. press ENTER to continue.
```

FIG. 17. Display of consultation screen for parameter RJAW, ranked junction angle.

CONCLUSIONS

A modest attempt was made to develop a drainage pattern identification system to utilize the power of the expert system shell. This system demonstrated the potential for adopting parameters and rules from previous work of experts, and enhancing their utility with a shell approach. The result was a practical tool to assist users in determining drainage pattern types given appropriate information on the parameters. The system is easy to use, and, whenever necessary, window-oriented explanations are presented to provide assistance. It is also capable of interfacing with external packages, including graphics software. The expert system and shell features 15 production rules that lead to determination of drainage pattern types, such as the example of the rectangular drainage pattern presented here.

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```
REMOTE-SENSING

Please provide the value of RMA12

   SACUTE : (MA12 < 35 AND SD12 < 14)

   SACUTE
   UNKNOWN

 1. Use arrow key or first letter of item to position the cursor.
 2. press ENTER to continue.
```

FIG. 18. Display of consultation screen for parameter RMA12.

```
REMOTE-SENSING

Please provide the value of UNLEAF:
   NUNIF : (RMBYSD < 4.0)
   UNIF  : (4.0 < RMBYSD)

   NUNIF
   UNIF

 1. Use arrow key or first letter of item to position the cursor.
 2. press ENTER to continue.
```

FIG. 19. Display of consultation screen for parameter UNLEAF, uniformity of leaves.

```
REMOTE-SENSING

Please provide the value of TSHAPE
   STRAIGHT : (STRGHT < 2.5)
   CIRCUL   : (STRGHT > 2.5)

   STRAIGHT
   CIRCUL

 1. Use arrow key or first letter of item to position the cursor.
 2. press ENTER to continue.
```

FIG. 20. Display of consultation screen for parameter TSHAPE, shape of the trunk.

```
REMOTE-SENSING

Conclusions:
The type of drainage pattern is as follows:  MORE LIKELY RECTANGULAR

** End - press ENTER to continue.
```

FIG. 21. Display of consultation screen for the conclusion.

FIG. 22. Display of the rectangular drainage pattern.

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BOOK REVIEWS

Pioneers of Photography. Their Achievements in Science and Technology. Edited by Eugene Ostroff. SPSE, Springfield, Va., 1987. 318 illustrations, 285 pages, $65.00.

IN JUNE 1986, the Society of Photographic Scientists and Engineers held the First Congress: Pioneers of Photographic Science and Technology, in Rochester, New York. This book is a compilation of the papers presented there.

Like its subject, this book itself is something of a pioneering effort. It begins to bridge the gap between photographic technology and existing photographic histories. Too often these disciplines run parallel, each without notice of the other. Photographic technology moves forward with an eye fixed on the future, while photographic history looks back, focusing pri-