PHYSIOGRAPHIC REGION INTERPRETATION: FORMALIZATION WITH RULE BASED STRUCTURES AND OBJECT HIERARCHIES

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ABSTRACT

A conceptual scheme for the interpretation of physiographic regions, developed in an earlier effort, is formalized and programmed in Smart Elements resulting into a prototype knowledge-based expert system for physiographic reasoning, named TAX-4 (Terrain Analysis eXpert 4). An object-oriented model involving class-subclass hierarchies was formalized for the representation of factual and structural physiographic knowledge. A rule-base structure was developed for formalizing the strategic (inferential) knowledge needed for spatial reasoning which included physiographic context and landform identification. The terrain features of the site that are reasoned during execution (variables in the knowledge base that store the user's input) are formalized into objects. During execution the rule based tree structure performs a recursive search in the object-oriented representation of the study area, aiming to match the user inputs to a certain rule and consequently to the associated class description. If a match was successful a dynamic object was created and assigned at least to one parent class while part-of relationships to other objects could also be investigated and established. At the end of the execution, the set of dynamic objects represented the interpreted landforms and physiographic features in the study area.

1. INTRODUCTION

Mintzer and Messmore (1984) state that problem solving in landform interpretation commences with the interpreter formulating hypotheses about the landforms likely to occur in the study area, by drawing upon his experience and auxiliary information specific to the region. Then the interpreter searches the aerial image, to find a match between the observed characteristics and the expected pattern elements of each of the hypothesized landforms - as those exist in his mental models. Typical pattern elements examined include topographic form, drainage texture and pattern, gully characteristics, soil tone variation and texture, land use, vegetation, and special features (Way 1978). The interpreter continues this procedure, until all pattern elements are examined. If there is a significant match between the expected and observed pattern elements, the identity of the landform of the site is established. Otherwise, the next landform in the hypothesis list is investigated for a match.

Problem solving for landform and physiographic region interpretation is still an art (Argialas and Narasimhan 1988). The procedural framework for terrain interpretation problem solving is missing: books do not elaborate on the strategies needed to guide a novice to the terrain interpretation process through a step by step question and answer scenario. There is, therefore, a need to methodically study the physiographic and terrain-analysis reasoning process and, to better understand and formalize these processes and guide novice interpreters in terrain problem solving, develop computer-assisted interpretation procedures.

Knowledge-based expert-systems (KBES) are a field of artificial intelligence that addresses complex, domain specific, problem solving that requires unique expertise (Hayes-Roth et al. 1983). Knowledge-Based Expert Systems (Jackson, 1986) offer methods and tools for representing problem solving procedures within interactive computer programs and thus can assist in the discovery and formalization of terrain interpretation procedures. Expert system performance depends critically on facts and heuristics used by experts. Their success is largely determined by the effective computer representation of domain knowledge. Knowledge representation takes place by employing facts, objects, frames, rules, and inexact reasoning procedures.

In earlier efforts in constructing prototype expert terrain-related systems, knowledge related to landform physiographic context was not explicitly represented and used. Argialas and Miliaresis (1996) described a conceptual

scheme named TAX-4 (Terrain Analysis eXpert 4) that pertained to naming, describing and organizing detailed, "book-level" knowledge pertaining to physiographic regions (provinces and sections). In particular, the presented case study concerned typical terrain and landforms of the Basin and Range Province of Southwest USA (Fenneman, 1931; Peterson, 1981). Building this new physiographic expert system involved identifying, naming, describing, and organizing knowledge pertaining to physiographic regions (provinces and sections), and their component features in terms of their distinguishing indicators. These indicators were defined so as to reflect the distinctive characteristics of each newly defined class. The synthesis of the various indicators encompassed a study of physiographic books and reports and it was achieved through a heuristic abstraction approach, and trial and error experimentation (Argialas and Miliaresis 1996; 1997a). The compiled factual and structural descriptions were represented by using appropriate definitions of class-subclass hierarchies (Argialas and Miliaresis 1997b).

This paper presents the formalization and implementation of the conceptual scheme of TAX-4 in the hybrid expert system shell Smart Elements (that supports both a reasoning system and a powerful, object-oriented representation), resulting to a knowledge-based expert system involving physiographic context identification.

2. METHODOLOGY

In the developed expert system, an object-oriented model was programmed for the representation of the factual and structural physiographic knowledge that included classes, subclasses, and dynamic objects. Classes represented the knowledge being reasoned on by the rules and dynamic objects described variables in the knowledge base.

2.1 Study area

The methodology was implemented for the Basin and Range Province of Southwest USA. It is centered principally on the State of Nevada. It is a large area, approximately one tenth of the USA, occupied mostly by wide desert plains, generally almost level, interrupted by great, largely dissected, north trending, roughly parallel mountain ranges formed by a series of tilted fault blocks (Fenneman 1931). The Province of Basin and Range is further subdivided to five sections, each at a different erosion stage, such as the Great Basin (mainly in the youthful erosion stage) and the Sonoran Desert (maturity erosion stage) (Fenneman, 1931).

2.1 Class and Object hierarchies

The various subclasses and objects of the Basin and Range Province and their distinguishing indicators and their attribute values were given by Argialas and Miliaresis (1996). The spatial components of a Province are the Physiographic Features (Intermontane Basins), Topographic Forms (Basin Floor, Piedmont Slope), and landforms (alluvial fans, playas, pediments) (Argialas and Miliaresis 1997a). Spatial terrain decomposition was achieved by partitioning each physiographic section into its component physiographic features, and each physiographic feature into its component topographic forms, and each topographic form into its component landforms. More specifically three class-subclass hierarchies (kind-of) were developed:

1. The Physiographic Province hierarchy that contained as member class the Basin & Range Physiography that was further sub-divided to Youthful and Maturity Erosion Stage.
2. The Physiographic Feature hierarchy that contained the Intermontane_Basin class that was further subdivided to Bolson and Semi-Bolson type.
3. The Topographic Form hierarchy that contained two classes, (a) Basin-Floor and (b) Piedmont Slope.

The dynamic objects of provinces, physiographic features and topographic forms form part-of relationships, as follows: a landform object is part of a topographic form object, a topographic form object is part of a physiographic feature object, etc. (Argialas and Miliaresis 1997b). Having defined the classes, subclasses, objects, and component objects we used them to describe the inferential and strategic knowledge through a rule-based formalism as explained in the following.

2.2 Inferential and Strategic Knowledge Representation

The rule-base structure for representing the strategic (inferential) knowledge needed for spatial reasoning included three distinct aspects:

1. physiographic context identification,
2. landform identification for a known physiographic context,

3. physiographic context identification from either a known landform, or topographic form or physiographic feature.

The conducted inference process was either forward or backward and it could involve many levels of reasoning depth and many rules and class hierarchies thereby providing a way to search through member classes in order to identify the dynamic objects (features of the site) that met a specific rule condition.

The dynamic objects of certain classes - representing the terrain features of the site being interpreted - were linked during execution with part-of relationships. For example, Basin floor object 1 and Piedmont slope object 1 are part of Intermontane_Basin object 1 that is part of the object Basin and Range Province USA Youthful stage 1 (Great Basin).

In a search of the possible alternative scenaria for problem solving in physiographic analysis we have conceived four distinct aspects of strategic physiographic reasoning:

a) Physiographic Province and Section inferencing and refining to either youthful or maturity erosion stage by specific physiographic indicators,
b) Physiographic Feature inferencing by their indicators,
c) Topographic Form inferencing by spatial association and
d) Landform inferencing (alluvial fans, playas, pediments, valley fill, etc.) by pattern elements, geomorphologic indicators, and spatial association to interpreted landforms.

The implementation of these strategies was as follows. Rules were developed inferencing physiographic regions (provinces and sections) from their physiographic indicators. Besides the rules for inferring a physiographic concept at the level of a province, rules were developed, following a method of conceptual refinement, which refined the concept of the province to that of a physiographic section of that province. Conceptual refinement implies that the rules inferring a subsection are more specific (involving detailed characteristics) in contrast to the rules inferring a section using the more general characteristics of the province. In the case of the Basin and Range concept, the refinement rules inferred the concept of a youthful (Great Basin) or mature erosion stage (Sonoran Desert).

Once a physiographic Province or Section was inferred and/or refined by physiographic indicators, the system queries the user for the identification of the possible physiographic features that could be evident in the study area. If a physiographic feature (e.g. an Intermontane Basin) is inferred based on the user's input of the relevant indicators, the possible types of topographic forms that could be evident within that physiographic feature are posed for examination to the user. If a topographic form is inferred then the user will be guided for the identification of the expected landforms within that topographic form according to user-specified pattern elements and spatial constraints (direction, spatial relationship, and condition).

During consultation of the expert system, the user is asked by the system to select the reasoning process and the indicators of each terrain unit to be evaluated.

2.3 Formalization of Physiographic Knowledge with Nexpert Object

The earlier developed object oriented representation structure and the associated inference rules were programmed in the expert system tool NEXPERT OBJECT (recently renamed to Smart Elements). Nexpert Object (Neuron Data 1993) provides a graphical representation of both the object and rule structure as it exists before the program execution or as it unfolds during the dynamic consultation of the expert system. These graphical networks are more declarative than the alternative textual representations and therefore they are used in the figures to demonstrate the system operation.

The inferential knowledge for determining the physiographic context of the Basin and Range Province was expressed in rules. Recursive structures (do loops) and AND-OR tree hypotheses were implemented (see Figure 1). During execution the rule based tree structure performs a recursive search in the object-oriented representation of the study area. During an iteration a different path is followed according to the user inputs limiting the search to a specific problem solving scenario (e.g., forward physiographic context identification). The aim is to match the user inputs (for example, physiographic context properties) to a class description (for example, Basin and Range maturity stage). At the end of an iteration a dynamic object (PH_1=Sonoran Desert) was created and it was assigned to at least one parent class (a kind-of relationship) while part-of relationships to other objects could be investigated and established. Finally a set of dynamic objects was created representing the interpreted landforms and physiographic features in the study area.

Figure 2 shows a graphical representation of a typical rule for establishing the Basin and Range province. Any rule like this in Nexpert Object is composed of three parts: the hypothesis to be established or rejected PH_Basin_and_Range in the right, the physiographic conditions in the left to be asked to the user in order to prove/disprove the hypothesis (e.g., frequency of mountain ranges, presence of desert basins), and the 'Then' actions of the rule, shown to the left with the prefix "+=>", executed if and when the rule fires. Once the hypothesis of the Basin and Range is established, a rule (see Figure 3) is triggered by the hypothesis PH_Basin_and_Range_Refinement that refines the Basin and Range context to either Maturity (Great Basin) or Youthful (Sonoran Desert) Stage.

The outcome of a hypothesis that was proved true is the creation of a dynamic object e.g., an instance of the relevant class created during execution. A typical rule that creates dynamic objects is given in Figure 4. The class assignment is performed on the basis of the content of the variable dummy_task_PH that takes a value in the right hand actions of the rules that determine the physiographic context (see Figures 2 and 3).

Figure 1. The AND-OR rule-tree corresponding to the hypotheses PH_Basin_and_Range (right tree branches) and PH_Basin_and_Range_Refinement (left branches).
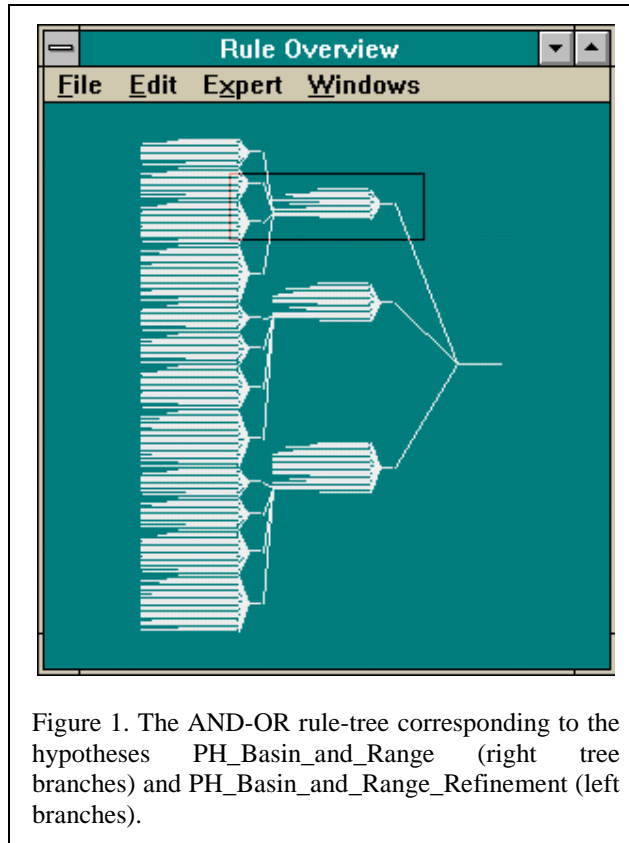
Figure 5 shows dynamic physiographic objects created during program execution. Classes and subclasses are shown in circles while the class-subclass relationships are shown with links (lines) connecting a class (circle) with another class. Class properties are indicated with the little squares, while inherited properties are shown replicated in the subclasses as they appear in the parent class. Dynamic class instances (objects) are shown as little triangles and they are created during consultation. They are assigned (linked) to the proper class they belong to based on the inference process. We observe that the dynamic object PH_1 derived by the rule in Figure 2 was assigned to the class Basin and Range. The dynamic object PH_2 was derived by the rule in Figure 3 and it was assigned to the class Basin and Range Youthful Erosion Stage (Great Basin Section).

In Figure 6 we see that the various dynamic objects interpreted during later inference stages were linked to the object PH_1 with a part-of relationship. More specifically a physiographic feature (PF_1: an intermontane basin of bolson type) is part of PH_1. PF_1 contains two topographic forms TF_1 (Piedmont plain) and TF_2 (basin floor). More dynamic objects corresponding to landforms are linked to the topographic forms. So the dynamic object LF_1 is a kind-of alluvial fan established from pattern elements (LF_Alluvial_Fan_PE), geomorphologic criteria (LF_Alluvial_Fan_GM), and spatial association criteria (LF_Alluvial_Fan_SR). At the same time LF_1 is part-of the topographic form TF_1 which is a kind-of Piedmont plain. TF_1 and TF_2 (basin floor) are part of the physiographic feature PF_1 that is a kind-of intermontane basin of bolson type.
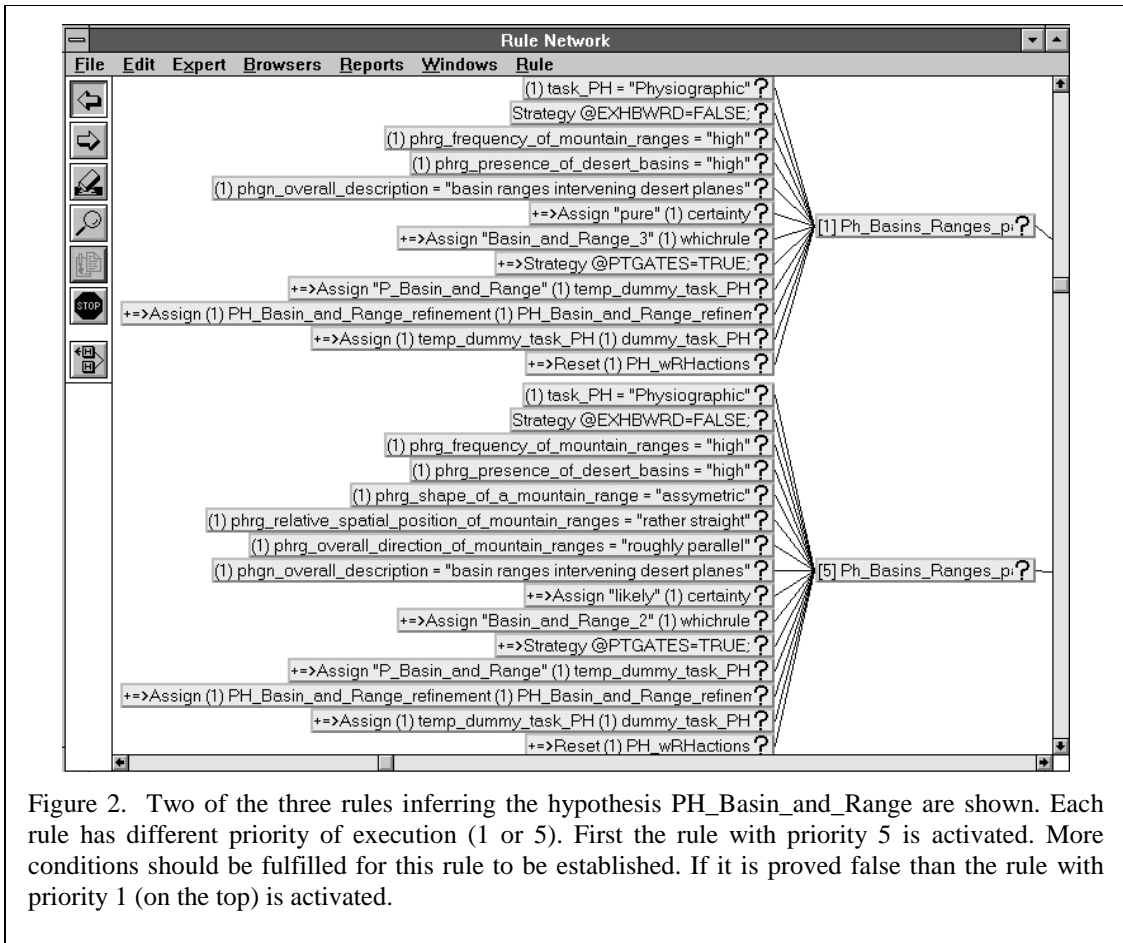
Figure 2. Two of the three rules inferring the hypothesis PH_Basin_and_Range are shown. Each rule has different priority of execution (1 or 5). First the rule with priority 5 is activated. More conditions should be fulfilled for this rule to be established. If it is proved false than the rule with priority 1 (on the top) is activated.
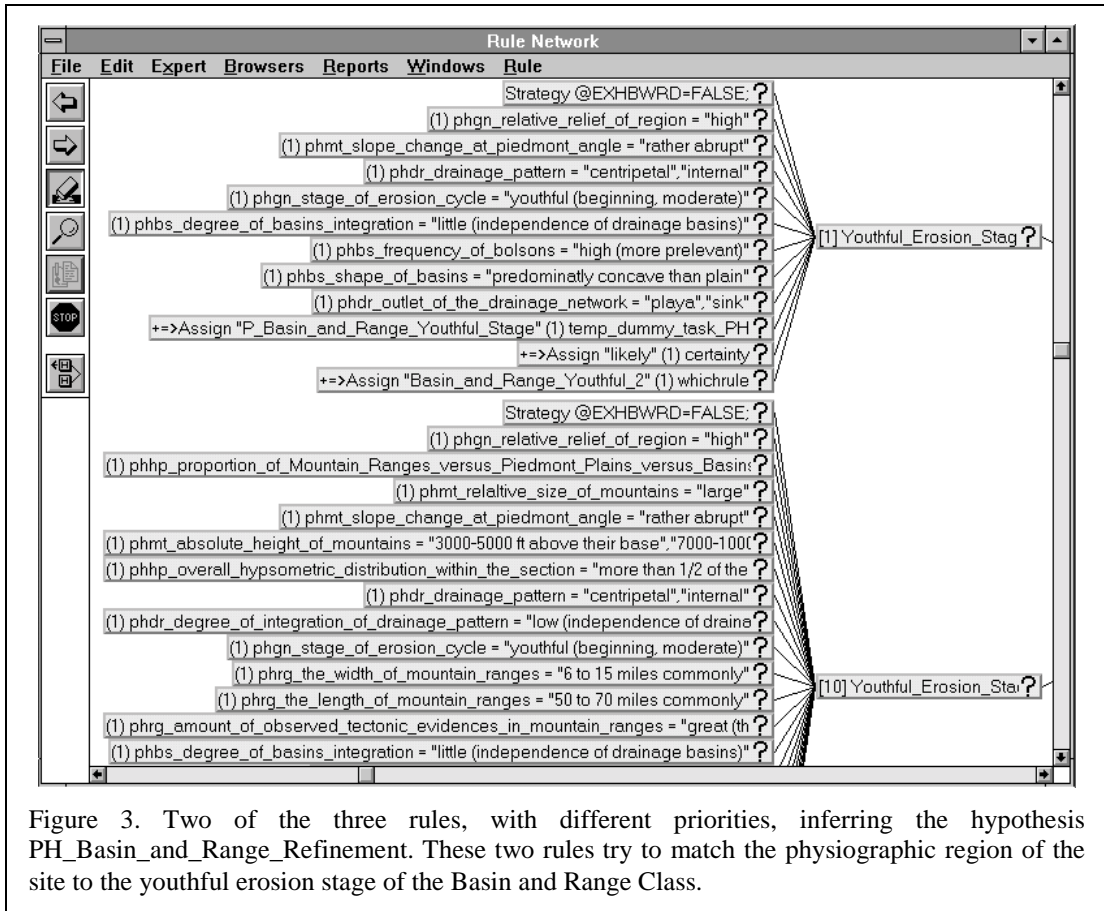

Figure 3. Two of the three rules, with different priorities, inferring the hypothesis PH_Basin_and_Range_Refinement. These two rules try to match the physiographic region of the site to the youthful erosion stage of the Basin and Range Class.
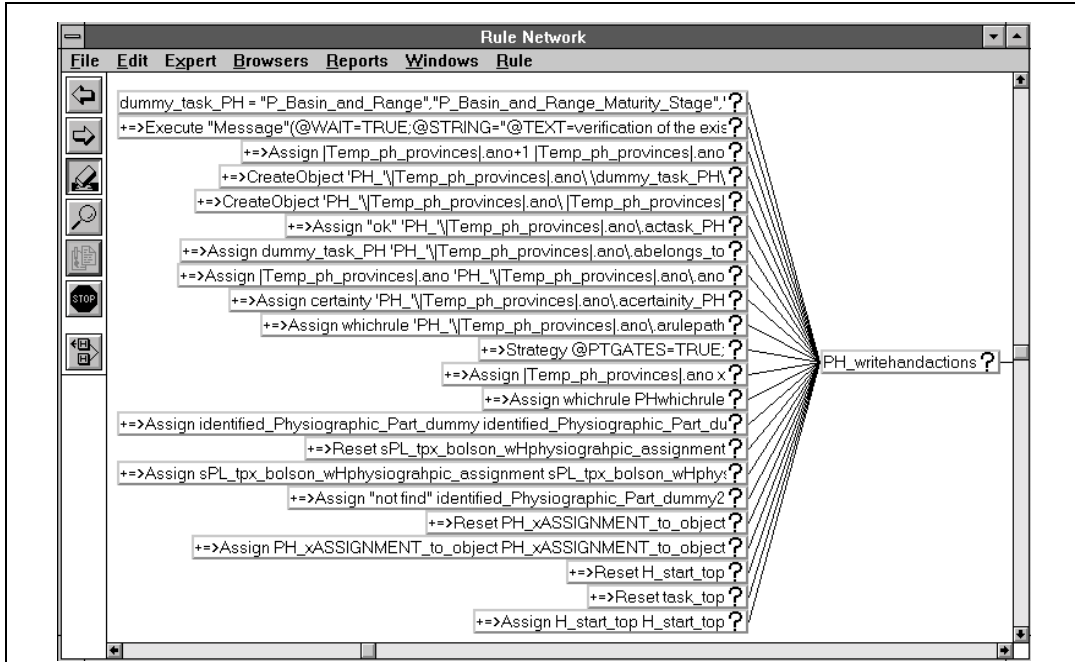
Figure 4. Rule that creates the dynamic objects corresponding to the physiographic province and section classes. The class assignment is performed based on the value of the variable dummy_task_PH that can take the values: 'P_Basin_and_Range', 'P_Basin_and_Range_Youthful_Stage', etc.
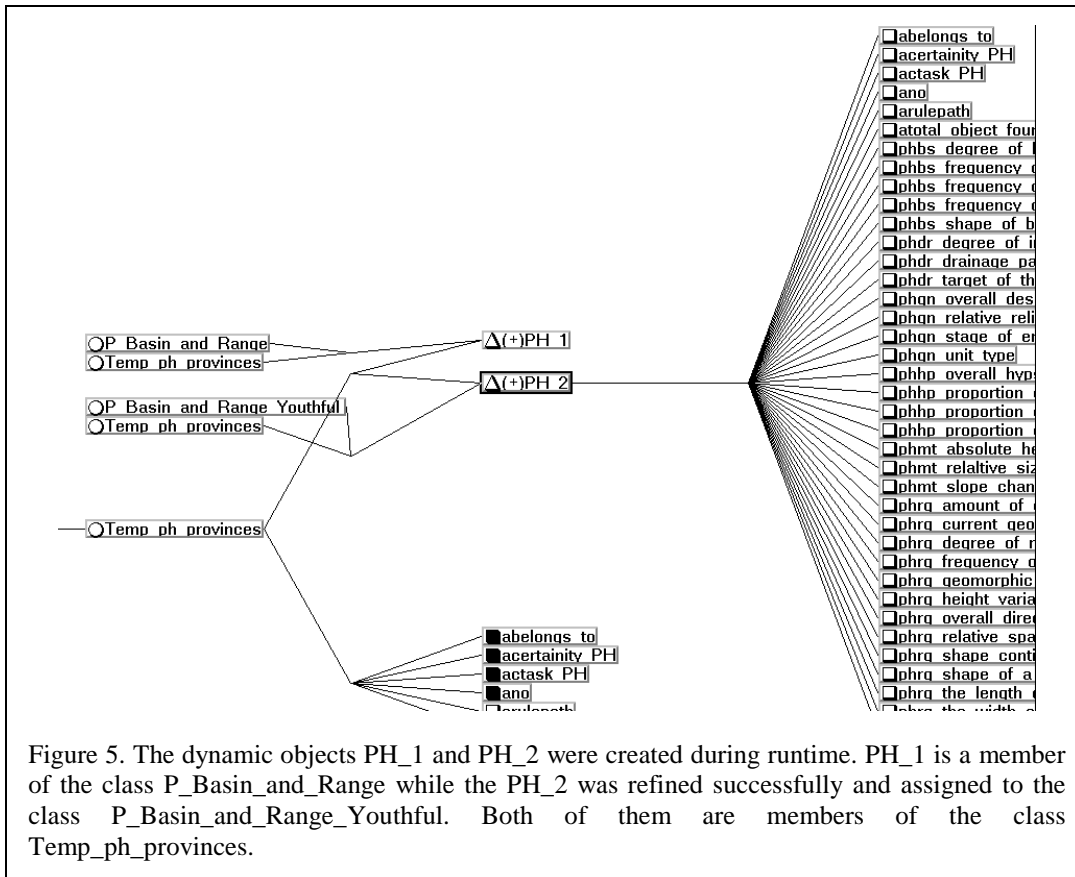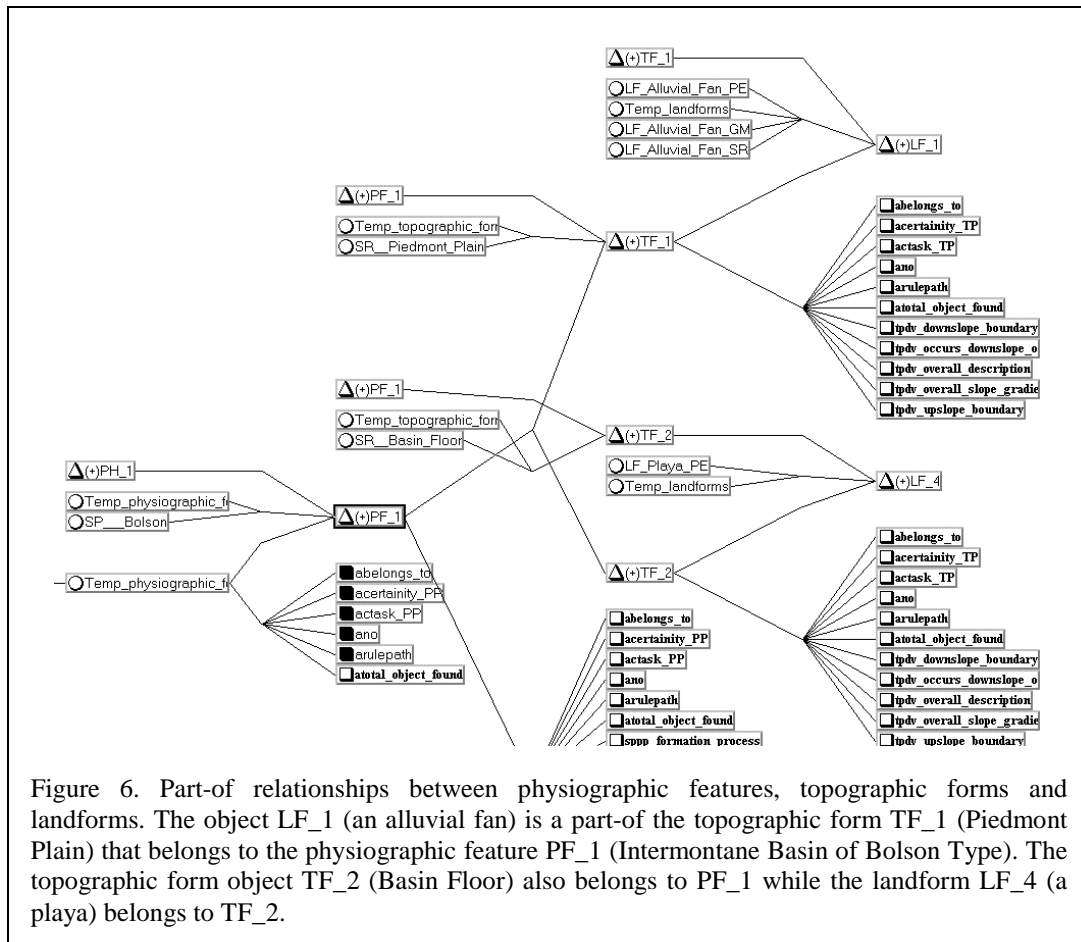

Figure 5. The dynamic objects PH_1 and PH_2 were created during runtime. PH_1 is a member of the class P_Basin_and_Range while the PH_2 was refined successfully and assigned to the class P_Basin_and_Range_Youthful. Both of them are members of the class Temp_ph_provinces.

Figure 6. Part-of relationships between physiographic features, topographic forms and landforms. The object LF_1 (an alluvial fan) is a part-of the topographic form TF_1 (Piedmont Plain) that belongs to the physiographic feature PF_1 (Intermontane Basin of Bolson Type). The topographic form object TF_2 (Basin Floor) also belongs to PF_1 while the landform LF_4 (a playa) belongs to TF_2.

3. CONCLUSIONS

The TAX-4 formalization in the expert system tool NEXPERT OBJECT was successful and allowed the representation of both the complex rule structures and the terrain classes and object hierarchies. The inferential knowledge was expressed in rules through recursive structures and AND-OR tree hypotheses and allowed the repetitive photointerpretation of the terrain features at various scales during successive sessions. During each iteration different paths were followed according to the user inputs that limited the search to a specific problem solving scenario. The various terrain features of the site, interpreted during consultation, were linked to each other with part-of relationships that represented the framework of spatial organization in the developed Basin and Range physiographic context.

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