ACES: A Cartographic Expert System

C. Pfefferkorn, D. Burr, D. Harrison, B. Heckman,
C. Oresky, and J. Rothermel
ESL, Incorporated
495 Java Drive
Sunnyvale, CA 94086

ABSTRACT

ACES is an expert system for labeling maps. In developing ACES an attempt was made to capture the expertise cartographers use in the labeling process. This expertise includes how work is organized, what techniques are applied in specific situations, and how those techniques are selected. To accomplish a labeling task effectively the system must also make use of task specific information which cartographers also evaluate. ACES is a system still under development that can currently solve moderately complex map labeling tasks involving point, line, and areal features. ACES also provides a general planning framework which can be tuned for varied graphic labeling applications.

INTRODUCTION

Cartographic products are used in support of a number of activities: nagivation, operation of various networks and systems, and the exploration for and management of natural resources, to name a few. To a great extent, cartographic composition is performed using conventional manual techniques which are extremely labor intensive, with the process of feature labeling consuming much of the cartographer's time and effort.

To produce quality maps, cartographers make many labeling judgements using techniques which may vary both by product and specific situation. In applying judgement, cartographers may be allowed to generalize, smooth and exaggerate features, move and delete symbols, or modify placement strategy while incorporating various aesthetic considerations.

In order to significantly automate the production of publishable maps, it is necessary to model the expertise of cartographers within the computer. Artificial Intelligence (AI) design structures help accomplish this modelling task by manipulating internally the symbolic representations of those patterns and interrelationships of placement "rules" which are used by cartographers.

To facilitate the development of AI systems, a number of knowledge engineering tools have been developed, including: object oriented programming, rule based systems, automatic storage management, sophisticated programming environments, and powerful man-machine interfaces (raster graphics, window managers, menu packages, extended keyboards and peripherals).

The first section of the paper describes the problems of the cartographer, the second describes how ACES was designed based on AI techniques. An example follows which demonstrates current results, conclusions put the work in perspective, and future development is discussed.

CAPTURING EXPERTISE

"For 150 years, distinct rules concerning type placement spread among topographers and cartographers by word of mouth. The master taught his journeyman and the latter inculcated them in his apprentice..." (Imhof 1975)

The initial step taken to define a working set of map labeling heuristics, and hopefully facilitate the process of inculcation mentioned by Imhof (Imhof 1975), was to identify what expertise was required by cartographers to successfully label a map. How is the work planned? What generic and specialized techniques are considered for use, and why are specific ones chosen over others?

Analysis indicates that cartographic type and label placement is governed by four factors:

(1) Generally accepted cartographic rules
(2) Organizational requirements and standards
(3) Individual style and "rules of thumb"
(4) Mediation by internal review

From map to map, or project to project, the knowledge base (cartographic rules, product dependent specifications, etc.) required to successfully accomplish the labeling task is reorganized into three parts:

(1) General procedural knowledge
(2) Task specific knowledge
(3) Heuristics based on "rules of thumb"

ACES employs a general procedural knowledge base* which provides guidance for situations which vary from the most simple problems of point symbol labeling, to the most complex, involving all three major feature label types (point, linear, and areal). Incorporation of a task specific knowledge base helps resolve those problems associated with a defined set of labeling requirements.** Yoeli (Yoeli 1972) describes the cartographic-geographic criteria for "easy

---

* For example, start with area labels, which are the most constrained.

** Product scale dependent symbology, font, text sizes, etc. For example, where should a product standard symbol be placed, and what variations in font, size, and orientation are permissible?

legibility and identification of the map names" as:

(1) Precise graphic relationship between the name and the relevant item.
(2) Minimum of mutually disturbing interference between the names and the other contents of the map.
(3) Application of didactical principles, i.e. the placement of the name in such a way as to amplify, if possible, the characteristics of the items named (e.g., flowing placement of river names, etc.).

What individual techniques, or "didactical principles", cartographers bring to bear for optimal label placement are often transferred informally and are best described as "rules of thumb". The potential to incorporate these informal rules is realized via the ability to include heuristic software modules that can be selectively accessed and modified, depending on varying placement considerations. The ability to combine generally defined, task variable, and floating rule of thumb knowledge bases provides ACES with a symbiotic capability for cartographic labeling tasks.

PROBLEM SOLVING

To capture the expertise of cartographers, it is necessary to represent the potential decisions they make and provide a problem solver for searching through these potential decisions. The ACES problem solver is based on a well known heuristic search method which can be characterized as a process of searching through a tree whose nodes are situations and whose branches are operations on those situations (Newell 1969; Hewell & Ernst 1965; Newell & Simon 1963, 1972; Nilsson 1971; Simon 1971; Slagle 1971; Pfefferkorn 1975).

In ACES the situations are subproblems consisting of a set of map entities or "mapnodes" to be labeled, and the operations are strategies or "actions" that can be applied to the subproblems to accomplish the labeling.

KNOWLEDGE REPRESENTATION

The knowledge representation used by ACES can be divided into three parts: mapnode description, interaction graph, and a decision or design tree.

The mapnodes description represents mapnode attributes such as location, type, icon, label text and font, influence rectangle and possible label positions. This information is used to develop an interaction graph which consists of a set of pointers. Each pointer connects two mapnodes to indicate that their influence rectangles overlap. An influence rectangle is the region which encloses all possible label positions for a mapnode. The generated interaction graph is used for planning and checking of potential label overlap.

The decision tree is used to control the search behavior of the ACES problem solver. It contains a history of what strategies have been tried and where the problem solver can continue its exploration. Figure 1 illustrates an example of an ACES decision tree.

PROCESSING SEQUENCE

Before executing the map labeling actions, the initialization procedure computes the following for each mapnode: possible label positions, influence rectangles, the interaction graph, and a class priority rating. The priority rating is computed for each map object (with associated mapnode) based on a user defined class lattice as illustrated in Figure 2.

All possible mapnode label positions stored within ACES have been chosen from several cartographic labeling studies. (Imhof 1975; Freeman & Ahn 1983; Yoeli & Loon 1972; Hirsch 1982).

Area feature labels are processed first because they tend to be the most constrained (Yoeli, 1972), followed by point, and then linear label placement. *

For areal features, potential label positions are computed based on each feature's particular shape and size. Positions can be determined using various algorithms (e.g. weighted centroid, skeletonization), and if the feature crosses a minimum area threshold, additional positions can be located around the perimeter.

Currently, point features have sixteen potential label positions depending on class priority, with optional provisions for multiple line placement when necessary. Point processing includes a comparison with the area labels which have been previously placed.

Linear (and curvilinear) placement can be computed using parameters based on the feature's shape and size, as well as priority rating and any guides or rules for placement (USGS, 1963).

Once the possible label positions for a mapnode are determined, the system calculates the mapnode's influence rectangle. After all the influence rectangles have been computed, all possible label positions for point feature icons, areal boundaries, and symbolized linear features are checked for overlap. If an overlap is detected, information is gathered concerning which features are overlapped and where the overlap occurs. This information is stored in the interaction graph. Using the interaction graph, the system thus computes the nearest neighbors for each mapnode. A nearest neighbor is defined as any node whose influence rectangle overlaps the influence rectangle of the initial node.

---

* Implementing areal feature labeling in this manner is an example of starting with a simple strategy, and expanding the approach based on emperical results.

Using this stored information, the labelling process begins. Adjustments are performed iteratively until all feature classes have either been placed successfully, or identified in a set for remedial action. Currently, remedial processing is performed automatically after all classes have been processed.

CONCLUSION

The current ACES system has demonstrated that much of the map labeling process can be automated (see Example 1). The current system is experimental and effort is required to produce a production quality system. We are continuing the exploration of applicable AI and graphics processing approaches before any effort is made to produce such a system. The ACES planning framework provides: a capability to focus appropriate strategies that are applicable to different problem sets, the use of techniques in priority order until one is successful, the ability to split problems into subproblems, and an ability to handle the successful and unsuccessful application of various strategies. Specific rules governing action strategies may be developed for each new application.

FUTURE DEVELOPMENT

It is clear to us that many of the AI techniques utilized in ACES are applicable to many other cartographic tasks. The generation and placement of symbolized graphics from multi-scale attribute data bases is one associated application. Other potential directions include map recognition (pattern processing), featurization, and scale dependent or product specific data extraction and generalization.

AI techniques are also applicable to many related tasks involving the differential processing and presentation of graphic and symbolic data. Annotation of any kind of image or graphic data, be it a map, engineering drawing, or business chart, could be performed with application development of the existing ACES system.

REFERENCES

Freeman, H. & Ahn, J. 1983, A Program for Automatic Name Placement: Autocarto Six (Proceedings of the 6th International Symposium on Automated Cartography), 444-453.

Hirsch, S. 1982, An Algorithm For Automatic Name Placement Around Point Data: The American Cartographer, Vol. 9, No. 1:5-17.

Imhof, E. 1975, Positioning Names On Maps: The America Cartographer, Vol. 2, No. 2:128-144.

Monmonier, M. 1982, Computer Assisted Cartography. Englewood Cliffs, NJ: Prentice Hall.

Newell, A. 1969, Heuristic Programming: Ill-Structured Problems. In Aronofsky (Ed.): Progress in Operations Research,, Vol. III, New York: Wiley.

Newell, A. & Ernst, G. 1965, The Search for Generality, IFIPS65, 17-21.

Newell, A. & Simon, H.A. 1963, GPS, A Program That Simulates Human Thought. In Feigenbaum, E. & Feldman, J. (Eds.), Computers and Thought. New York: McGraw-Hill.

Newell, A. & Simon, H.A. 1972, Human Problem Solving. Englewood Cliffs, NJ: Prentice-Hall.

Nilsson, N.J. 1971, Problem-solving Methods in Artificial Intelligence. New York: McGraw-Hill.

Pfefferkorn, C.E. 1975, A Heuristic Problem Solving Design System for Equipment or Funiture LAYOUTS. CACM, VOL.18, NO. 5:286-297.

Sheil, b. 1983, Power-tools for Programmers. In Barstow, D., Shrobe, H. & Sandewall, E. (Eds.), Interactive Programming Environments. New York: McGraw-Hill.

Simon, H.A. 1971, The Theory of Problem Solving, IFIPS71, 249-266.

Slagle, J.R. 1971, Artificial Intelligence; The Heuristic Programm-ing Approach. New York: McGraw-Hill.

U.S.G.S. 1963, Map Editing and Checking. Topographic Instructions of the U.S.G.S., Bk 4, Chaps. 4C1-4C3.

Yoeli, P. 1972, The Logic of Automated Map Lettering. The Cartographic Journal, 9:99-108.

Yoeli, P. & Loon, J. 1972, Map Symbols and Lettering: A Two Part Investigation. Final Technical Report to European Research Office, United States Army, London, England, Contract Number DAJA37-70-C-2659, Technion Research and Development Foundation Ltd., Technion City, Haifa, Israel.

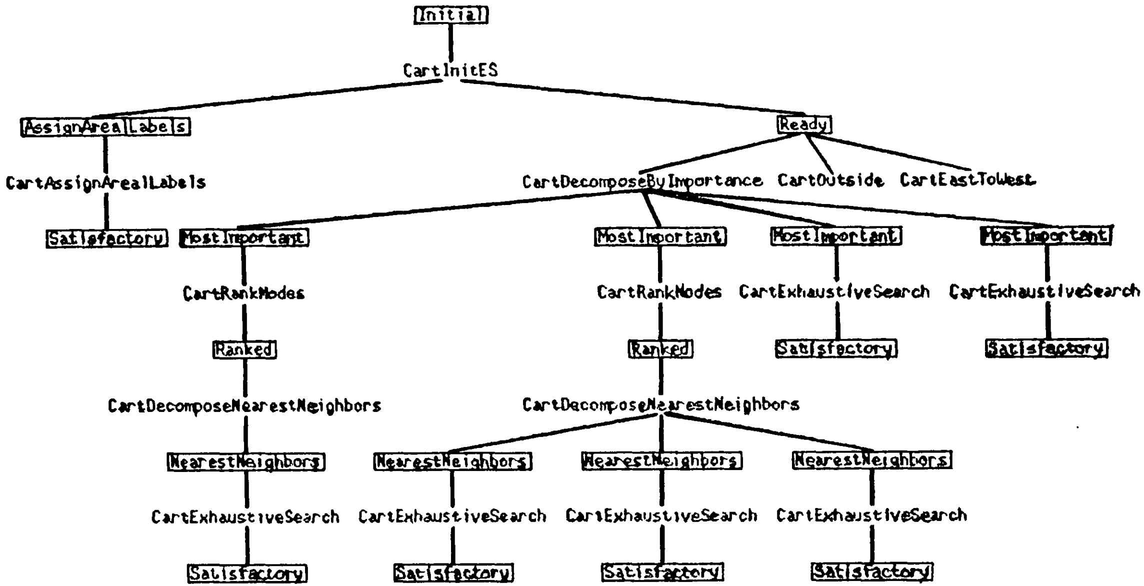


Figure 1: User Defined Decision Tree

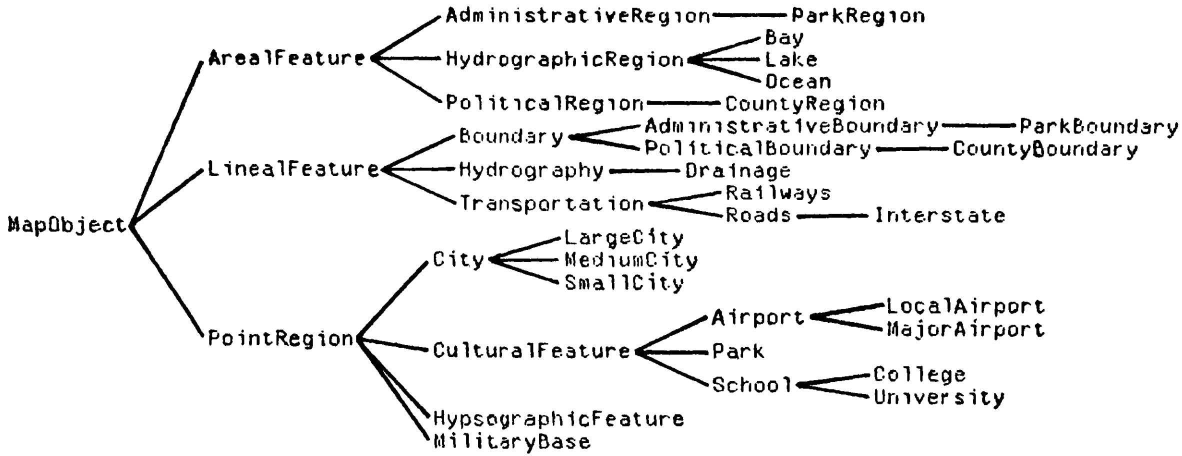
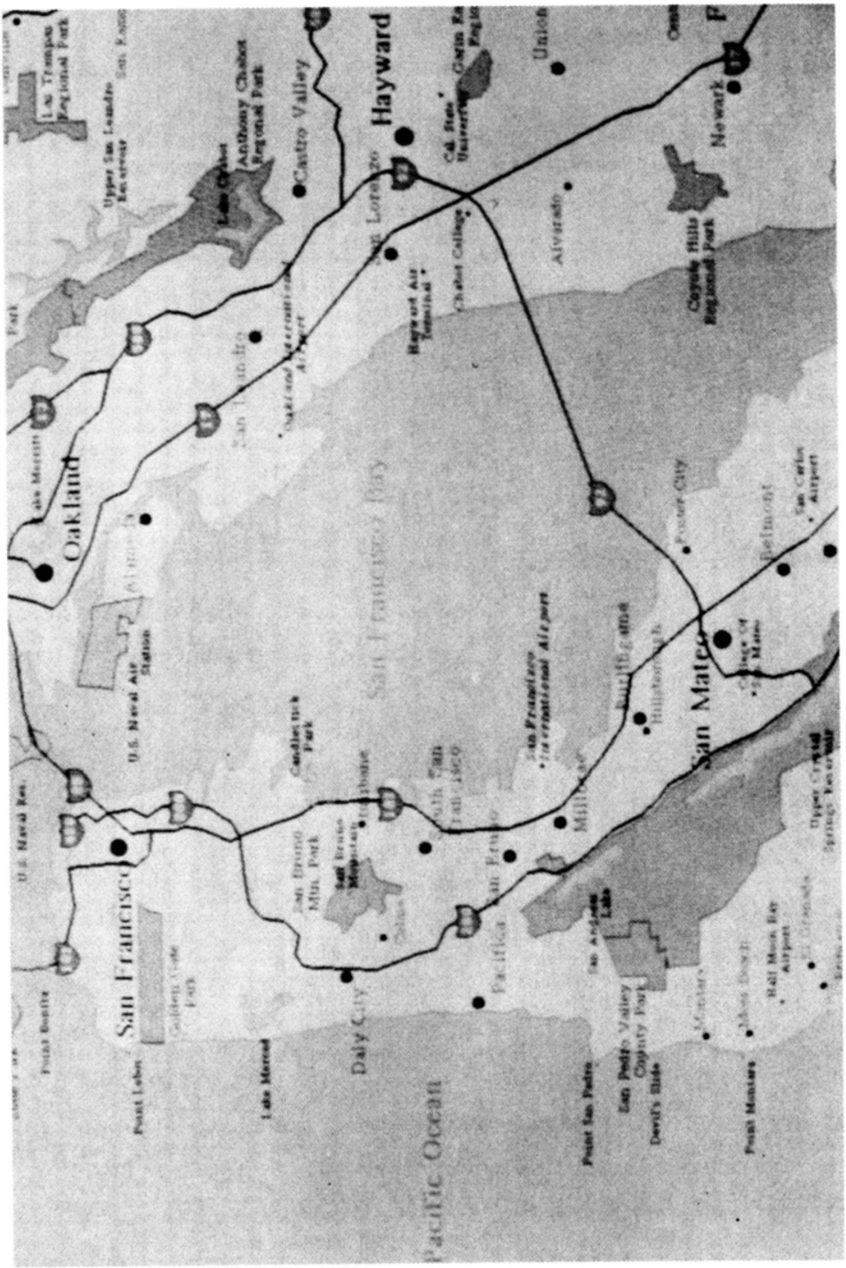


Figure 2: Defined Class Lattice



Example 1: Current ACES Product