Electronic Map Labeling

During the 1970s, as automated cartography became ever more adept at the application of computer graphics technology to the artistic rendering of linework and terrain, attention was increasingly given to the less well-defined problems. One of these, electronic map labeling (also called automated name placement) remained a challenging area of research through the end of the century. Like so many other interesting problems in automated cartography, the aesthetic placement of labels is determined by guidelines rather than rules. Succeeding generations of systems have dealt with various aspects of the problem from the creation of rule bases, data structures, and methodologies to the purely artistic application of the labels themselves.

In both concept and practice, electronic map labeling refers to procedures for fully automatic map-feature annotation. Although numerous digital illustration and map-composition tools offer functions that facilitate the manual placement of map labels, this article focuses on general trends in the development of rule bases, algorithms, approaches, and implementations for fully-automated systems. Among various online bibliographies that have helped coordinate research on automated name placement, the Map Labeling Bibliography maintained by Alexander Wolff, a computer scientist at Karlsruhe University, has been a notably valuable resource.

Most early papers on electronic map labeling relied on an article by Eduard Imhof for their methodological underpinnings. Originally published in 1962 in the *International Yearbook of Cartography* as "Die Anordnung der Namen in der Karte," the article was translated into English in 1975 for the *American Cartographer* as "Positioning Names on Maps." Drawing upon his lecture materials for a course offered on cartography in 1957 at

Eidgenössischen Technischen Hochschule Zürich, Imhof presented a set of rules for placing names for point, line, and area features. Each rule is presented succinctly and is accompanied by one or more clear illustrations of good and bad practices. Without anticipating later work on automated name placement, Imhof presented many of his rules in a way that made them eminently suitable for implementation in an expert system rule base. Directions are given for the placement of labels next to point references, with somewhat flexible preferences given to certain positions of the label relative to its referent symbol and its distance from it. Other types of rules are helpful at a systematic level. One such rule suggests beginning work at the center of the composition and working toward the edges to limit undesirable clustering of labels. Another suggests that placing the names of large areas on the map before placing those for point features will minimize label overlap.

Cartographic guidelines of governmental agencies are another source of rules for electronic labeling systems. The document *Technical Instructions of the National Mapping Division: Map Editing*, published by the United States Geological Survey in 1980, establishes numerous labeling rules that have been adopted in various automated systems. On the subject of "Positions for Lettering," the authors suggest prioritized label positions for point features comparable to Imhof's. Similarly detailed instructions are provided for labeling line and area features, with attention given to specific examples of features in each category.

Not until the work of Pinhas Yoeli in 1972 were such rules implemented in electronic labeling systems. His article, "The Logic of Automated Map Lettering," was one of the earliest to propose an algorithm for automated placement and present a testable implementation. Arguing that 50 percent or more of manual map production involved text placement, Yoeli identified two primary tasks of an automated system: the selection of names from a database and their subsequent placement. Believing the creation of a 'universal' geographical-name data bank to be beyond the scope of his paper, he focused instead on the second task, the development of label-placement algorithms for area and point features.

Yoeli believed that aesthetic solutions for area-name placement were more constrained than those for point-name placement. As a result, his system processed area names first, using variable letter-spacing to expand a name across its referent region. The subsequent placement of names of point features followed, with ordered preferences given to label positions relative to the referent symbol (**Figure 1**). The system made one pass through the name lists without guaranteeing to place all labels. Those left unplaced were identified for later manual positioning.

Yoeli referred to the placement rules of Imhof and others but chose to implement only those that were practical for the mainframe-computing and printing environments of the early 1970s. Other characteristics of his algorithm suggest further deference to the computing realities of the time. Although much of the methodology for his system seems to be drawn from the human cartographic experience, he did not provide a mechanism for repositioning placed labels as commonly practiced in manual cartography. Apart from Lisp or other list-processing languages of the day, few programming languages then supported the recursive mechanisms that simplify those types of backtracking solutions. It would have been possible, though awkward, to do so in FORTRAN. Because Yoeli did not mention the programming language he used, this effect on his implementation is not clear.

During the 1980s, as work in automated cartography migrated from mainframe computers to minicomputers, languages such as C and Pascal became popular development tools for automated name placement. Compared to previous FORTRAN and Basic implementations, C and Pascal offered sophisticated built-in tools for data-structure design and recursive-function calls. During that period a number of projects concerned with labeling point, line, and area features made extensive use of such programming tools to apply backtracking and other techniques borrowed from work in artificial intelligence.

Constraint propagation, one of the more popular of those techniques, saw the map document as a bounded plane upon which labels competed for space. Stephen Hirsch's (1982) point-feature-placement algorithm used an iterative approach that followed an initial, first-approximation placement of labels with a search for overlap. Labeling conflicts were resolved by repositioning an overlapping label along a vector pointing toward an unoccupied position weighted by placement desirability (**Figure 2**). The procedure ran until no further conflicts were found or until a maximum number of iterations had been reached. Hirsch's approach followed a gradient-descent model, characterized by the choice of an operation that provides the greatest improvement at each step. His work foreshadowed the optimization paradigm that came to dominate automated-name-placement research from the 1990s onward.

Herbert Freeman and John Ahn (1984) attempted to localize competition for map space by modeling neighborhoods of labels as a mathematical graph of connected components. Two features were identified as neighbors if their regions of possible label placements intersected (**Figure 3**). Starting with any unplaced point-feature label, the procedure chose a position for it and then considered label positions for its neighbors in a 'breadth-first' manner, by comparing its position with those of 'neighboring' labels. Placement within a given neighborhood ended once a suitable position was found for each of the features within it, preventing unnecessary processing in map regions beyond the local neighborhood.

As a fully annotated, finite map space is progressively reduced to a smaller scale, labels begin to overlap one another, inevitably forcing the cartographer to delete some of the labels and their referent features from the map composition. Practical name-placement systems are obliged to perform feature selection as well, through manual intervention or procedural mechanisms. James Mower (1986) introduced the use of ancillary data for making selection decisions for populated place features (such as cities and towns) based on their population. Using an object-oriented approach, map entities competed with each other for map space based on their relative importance. Using population as the ancillary-importance criterion, each feature adjusted its label position to avoid conflict with a more important feature. If none could be found, the feature deleted itself, thereby integrating label placement with feature selection, a key task in map generalization. Upon deletion, all of its remaining neighbors would reset their positions to the best possible placement and the competition would begin anew. Since a reset could only occur after the deletion of a feature, placements could not oscillate forever, guaranteeing that the procedure would finish. Mower later adapted this object-oriented system to a single-instruction-stream/multiple-data-stream (SIMD) parallel-computing environment in which each processor represented a competing feature and its label.

Rather than work with localized, constraint propagation procedures, Robert Cromley (1985) proposed a linear-programming relaxation method that modeled the problem as a weight-minimization function. Weights were defined as a ranked placement-desirability index from 1 to 6, with1 indicating the best placement position for a label and 6 indicating the worst. Although not purely automatic in its original form—some user interaction was allowed—he showed that an iterative-relaxation approach to linear programming could provide an efficient solution to the label-placement problem. Steven Zoraster (1986) constrained Cromley's linear programming approach to a 0–1 integer-programming problem and, like Cromley, made provisions for human intervention in his prototype.

Jon Christensen, Joe Marks, and Stuart Shieber (1992) provided a classification of earlier work in automated-name placement that encouraged the introduction of two new methods, the first based on gradient descent and the second on simulated annealing. A simulated-annealing approach provides an optimized solution through the minimization of a system's total energy. Arguing that many earlier techniques required solution times that increased exponentially as the number of data elements, they were among the first to compare implementations of their approaches to those of others, in this case with Zoraster's integer-programming solution and Hirsch's gradient-descent approach. They also provided a summary of the algorithmic complexity analysis of the name-placement problem, first suggested by the work of Robert Fowler, Michael Paterson, and Steven Tanimoto (1981) on the packing of the plane with rectangles. Their work made a convincing argument for the efficiency of a simulated-annealing approach in particular and for optimization approaches in general.

Hirsch inspired another line of research in automated name placement that developed in the late 1990s. Related to his use of vector-determined placement solutions, this strategy is sometimes called the ‘slider model.’ Most of the earlier point-feature-placement techniques used a discrete-position model, allowing only a finite number of placement positions surrounding a point feature. By contrast, Gunnar Klau and Petra Mutzel (2000) adapted Hirsch’s continuous-position model to aspects of Zoraster’s 0–1 integer-programming approach to create an optimal point-feature-placement algorithm.

In conjunction with the academic exploration of label-placement algorithms, several GIS manufacturers, most notably ESRI and MapInfo, have marketed their own automated-placement packages. Maplex, ESRI’s in-house offering, was developed from the work of Christopher Jones at the University of Wales at Glamorgan. Maptext, an independent company, offered several automated name-placement products for specific mapping domains including topographic, bathymetric, and aeronautical applications.

As the 1990s came to a close, the exploration of automated name placement had begun to move beyond the bounds of traditional applications and analyses. Several teams were investigating label placement in virtual and augmented-reality systems while others were finding uses for automated name placement in illustrative work for texts. Name-placement research seemed certain to grow into new, unanticipated areas with the proliferation of handheld and other mobile platforms offering sophisticated, multiuse graphic displays.

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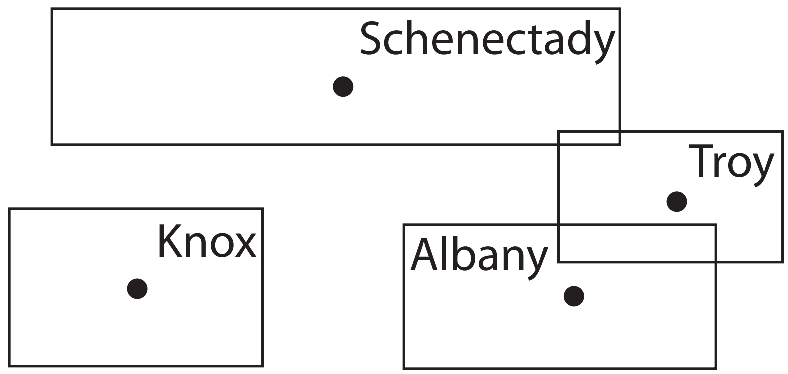
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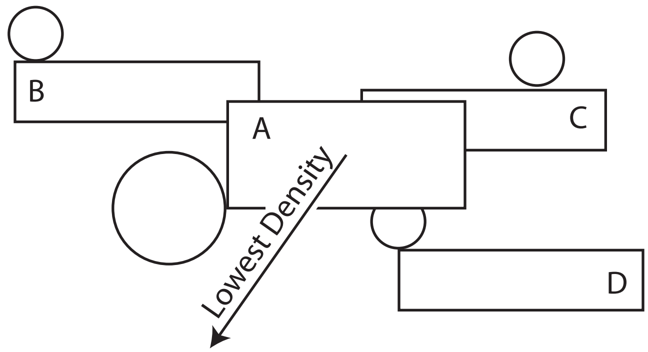
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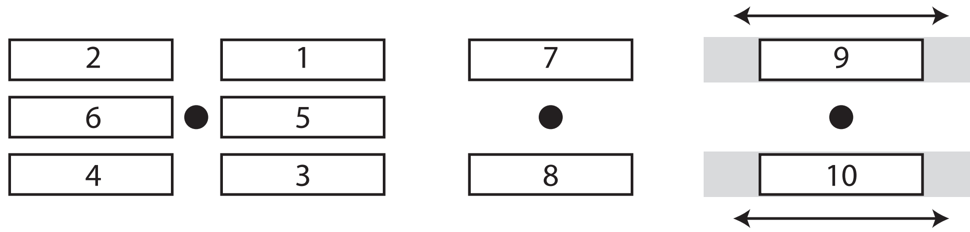
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