

Probability Graphics Support for Medical Reasoning

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ABSTRACT

Graphic displays of data from clinical observations and laboratory testing provide important support to the health practitioner in managing an increasing amount of complex information. This paper describes a graphic display program that preserves much of the context of data that is important to their evaluation, and maintains a sense of the strength of the signal when aberrant data are encountered.

INTRODUCTION

In managing data from clinical laboratory testing of an individual, the physician is faced with the daunting task of having in memory or at hand the reference ranges by age and sex, and perhaps race, for each test and by each method for each laboratory that furnishes test data to him. Furthermore, the user should be familiar with the analytic variance of each test in each such laboratory in order to evaluate the significance of changes in sequential tests and to interpret minor variations from reference distributions. Finally, though rule based interpretive systems have shown some promise, they have not captured the richness of context and goals faced by the physician, who is as often concerned with exclusion or confirmation of disease, its staging, severity, monitoring and response to therapy, as with the initial diagnosis.

Powerful support may be provided to the professional in the interpretation of complex data patterns through improved means of visualizing data in various contexts. Though the fundamental approaches described here were initially developed with bit-mapped plasma panels almost twenty years ago [1,2,3], there were no means for deployment in the clinical setting at that time; furthermore, emerging methods of human computer interaction such as high resolution bit-map devices, multiple interactive windows, and active graphics, may facilitate the development of interfaces that more correctly reflect the contextual reality of the reference ranges while retaining information as to the strength of the signal of aberrant results, and while also amplifying the natural pattern recognition skills of the human user.

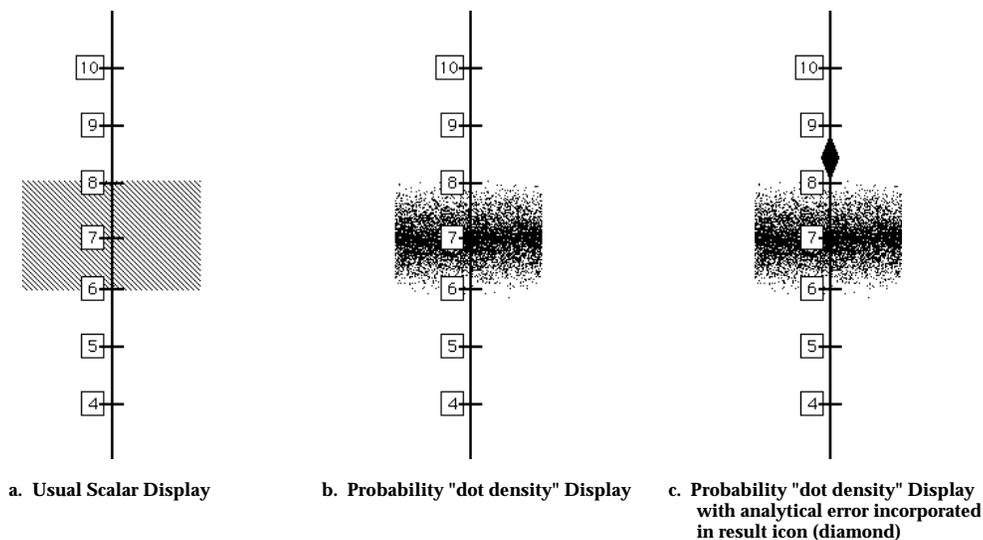
Some graphic presentations are themselves sufficiently complex that significant learning time is required of the potential user; this learning is often perceived to be worth the effort, particularly in areas of medical practice requiring high technology; it is seen in some nomographic and/or multidimensional displays, as with blood gas/ICU data, or with Kvitash diagrams. The presentation described here is more intuitive for the uninitiated in its basic components, only the polar multitest extension requiring a bit of "getting used to", in part because specific design implementations, as for specific sequences of scales, are somewhat arbitrary.

METHODS

The presentation of data discussed here is composed of 1) a probabilistic dot density representation of the reference ("normal" or "recommended") range rather than a sharply delimited range, 2) a plot of the measured value that also has a dimension that characterizes the analytic imprecision of the measurement and/or common types of periodic variability, and 3) a choice of horizontal trend displays of the same measure over time, or a polar representation and pattern of multiple test scales for measurements obtained simultaneously.

The first feature is illustrated in figures 1a and 1b. Figure 1a shows the usual scalar display, with unrealistically sharp definition of the reference range, followed by the probability "dot density" characterization of the reference range (figure 1b). The latter more realistically depicts the range of values from the reference population as a tendency for values to cluster around a central zone with population variance extending therefrom. It is immaterial whether such a derived range is calculated by the usual bell shaped curve (linear, logarithmic, ...), percentile distributions, "HOTH" (How Often That Happens[4]) or whatever, nor must the dots be plotted according to the distribution used in defining the range; its purpose is merely to indicate that any reference range represents a tendency for results from the population (or multiple measures from an individual) to cluster in ways that provide useful landmarks from which to evaluate deviation, and to indicate the magnitude of that deviation or "strength of the signal".

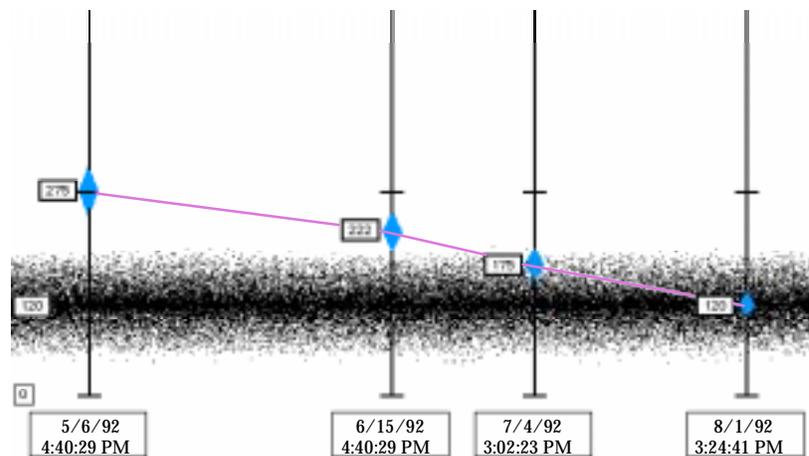
Figure 1: Comparison of Graphic Plots of Test Results



The second feature is illustrated in figure 1c. Over the background of the reference population distribution is next superimposed the individual test result, which also incorporates a representation of imprecision in the expected analytic error to yield a diamond shaped icon. The measured values are displayed via graphic (diamond) icons denoting the analytic, diurnal or other variance of interest associated with the data; when sequential results from the same test are plotted over time, the overlapping of sequential icons in the vertical axis indicates differences that are not significant, whereas non-overlapping indicates significant differences in sequential test results, at least in terms of the imprecision terms incorporated into the icon (figure 2). In figure 2, for example, each result is significantly different from its

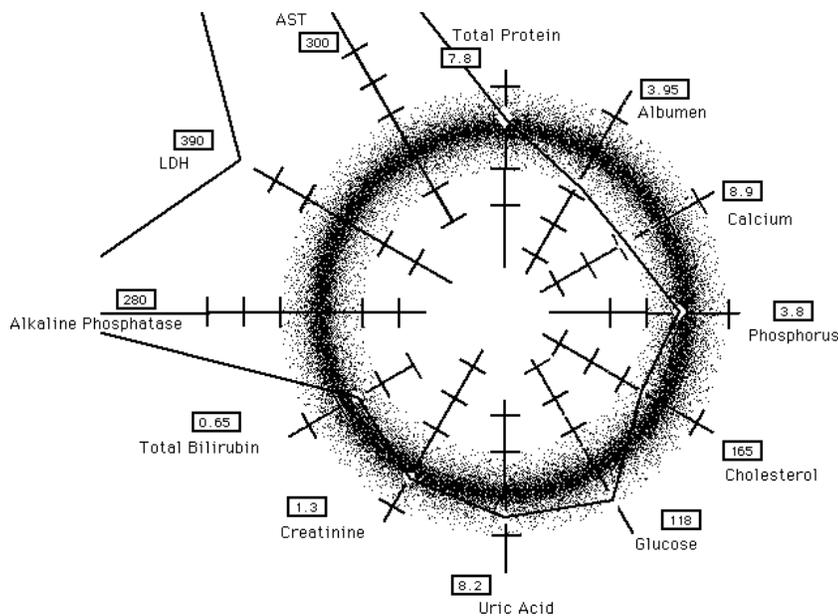
predecessor, but barely so. The height (vertical axis) of each diamond icon is proportional to the test value, as the variance is expressed as a coefficient of variation on a linear scale. As a practical matter, up to three different tests (each with its characteristic coefficient of variation) might be displayed on such a single horizontal trend display, particularly with icons of different color for each test; more than three tests on such a display becomes cluttered.

Figure 2: Test



Finally, normalization of the scales so that all reference ranges fall at the same place on all scales, permits arranging them in a polar "clock" fashion to yield patterns of several test results that may be characteristic of specific disorders, organ dysfunction, functional states, risk profiles and the like (figure 3). Thus, data from several different tests may be clustered together in a polar manner such that the shape and the skew of the profiles reflect meaning to the user. In order to produce effective patterns, the skew of which (eg. "northwest" pattern here) may be meaningful to the user, at least five simultaneous tests should be plotted but more than twelve tend to yield too much clutter. More importantly, the scales must be sequenced consistently for each interpretive (organ/functional profile) grouping for rapid learning. It might be noted that pattern profiles using plain polar coordinates (without the probability density features) have been used not only for professional communication at least since the work of Florence Nightingale, but also for communication of health risk profiles to laymen, notably in Japan[5].

Figure 3: MultiChannel Chemistry



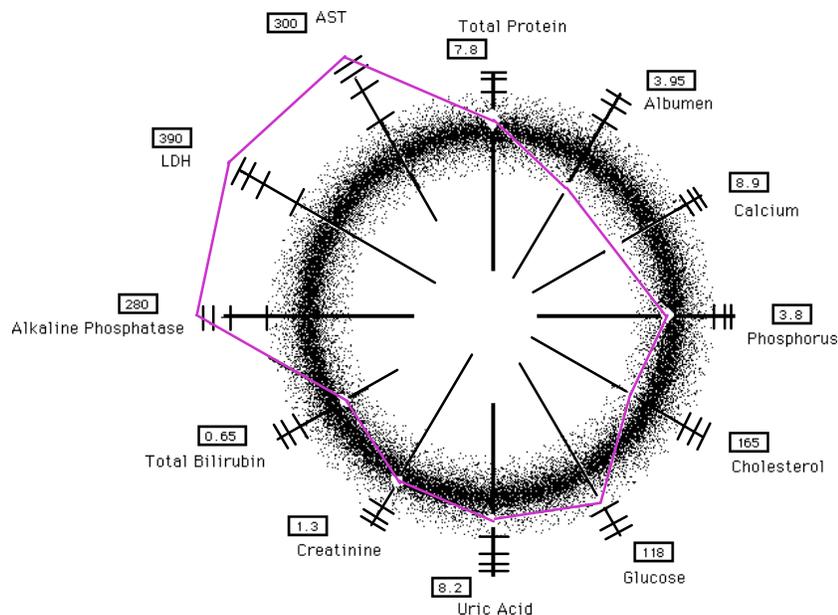
When test results are encountered that would be off scale in a linear scale presentation, the individual scale or all scales may be switched to a logarithmic presentation, as in figure 4. The scales may also be used to display other meaningful parameters derived from the primary data, as with ratios of test results, risk ratios and the like.

A major improvement over the earlier implementation has been the development of a powerful editor for routine customization of the displays by the user, even on a case-by-case basis. Versatile editing tools are provided for the user to configure the background probabilistic dot density functions and to edit the superimposed scales, either for classes of test patterns or for presentation of results from individual patients. These provide for several contexts for the display of results. These editing functions include:

- Selection of test or cluster of tests to be displayed
- Selection of temporal (horizontal trend) vs. pattern (polar, simultaneous test result) displays
- Selection of reference ranges for defining the background probabilistic reference cloud
- Selection or editing of number of test scales in either polar or horizontal displays
- Selection or editing of sequence of scales in polar displays
- Toggle selection of linear or semilogarithmic scales
- Toggle switch to turn on and off tick marks and/or scale values
- Selection of units for tick marks of scales, if any
- Selection of measure of variance or imprecision in result display icons

- Call-up of screens showing typical polar patterns in various diseases, using the same test scales and sequence of scales as the current tests displayed
- Click selection of specific patterns from these to generate other most discriminating test suggestions, as when the current display resembles two or more of the typical exemplary displays
- Call-up of rule based programs to suggest states or disorders matching the variants found in the current display(s)
- Editing of truth table test ranges and connecting logic to generate output statements, and generation and/or editing of output statements

Figure 4: MultiChannel Chemistry
(Log Normal Plot)



Some routine editing functions are table driven and automatic so that, for example, the reference range display is particularized to the age-sex-race cell of the subject of measurement, the analytic variance diamonds are particularized to the method(s) of measurement used and the like. Simple editing or user choices, as with two or three position toggle selections, may be indicated directly on the test display screen during observation.

Additional diagnostic and/or contextual support is provided by linkage to rule based inference systems, including truth tables and expert system based diagnostic inference aids. However, the power of the system is seen in the range of contexts provided, since the physician is as often concerned with ambiguous patterns, discerning the stage of disease, and the response to intervention, as with initial diagnosis.

DISCUSSION

The approach to diagrammatic probabilistic reasoning discussed here may be modified in a number of ways for related and unrelated purposes.

- In addition to the reference range(s) (particularized to the demographic population characteristics of the subject of measurement) displayed by the probabilistic cloud ("donut"), it may be used to display ranges typical for disease(s) or variant physiologic/periodic states and the like
- The reference range "cloud" may be derived from previous test results of the same individual rather than the population distribution
- For clinical research, another cloud representing actual measurements in numbers of patients with specific disease may be superimposed on the circular reference donut cloud to highlight variances typical, say, of those with coronary artery disease, over the background reference range
- Time may be expressed by degrees of rotation in a polar pattern rather than left-to-right in a horizontal display, but this mode often becomes too cluttered for the novice user
- In developing a consistent clockwise sequence of scales in polar displays, it is important to avoid sequences that often yield star patterns of test results rather than a consistent skew from the circular background, as star patterns are readily rotated in the perception of the viewer.
- For polar displays, there is often less interest in the values ticked on each scale than in the patterns themselves and/or in the strength of signal (deviation) relative to the reference range; hence the display of values of the scales or even of the test results may be toggled on or off.
- Since use of logarithmic scales may attenuate strength of signal information, an alternative choice is automatic adjustment of height of the reference range (decrease in vertical dimension) or in diameter of the polar "donut" representation of the reference range, so that markedly aberrant results remain on the screen. In some cases, extreme deviation from the reference range is itself diagnostically or pathognomically significant, though there may be little data on the differential diagnostic significance of lesser deviations.

The entire system is currently implemented on a Macintosh II platform, and some portions are available on the NeXT workstation.

SUMMARY

The system described here augments the interpretive skills of the user by using graphic displays of data that highlight meaningful features when confronted with trend data regarding an attribute over time or when faced with data reflecting multiple attribute measures simultaneously. Though the system has been developed for the medical professional user, applications are underway for monitoring of process control and powerplants, for psychological scaling, and for the display of nutritional information on food packaging.

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