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Metaphor graphics to support integrated decision making with respiratory data

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Overview

Support for data integration in the intensive care unit (ICU) often includes efforts to improve the display of data. An electronic version of a flowsheet (table of numbers) with optional line graphs is by far the most common format in current ICU computer workstation technology, yet there is little evidence that this format provides particularly good support for human integration of data. The present work introduces a new form of graphic representation, one that is far more metaphoric, far more tailored to the intensive care unit than a line graph. This graphic system, called *volume rectangles* represents mechanical ventilator data in such a way that it is easy to keep different types of variables conceptually separated, yet easy to see how they relate in a truly intregated way. Volume rectangles are one example of a general approach to display of data called the *methaphor graphic* approach, which is being evaluated in this and other contexts. Metaphor graphics are custom tailored visual displays designed to look like the real world situation from which the data is collected but not in a literal sense of 'look like'. Anecdotal observation suggests that such graphics are easy to learn, are remembered over long periods, and are good decision support tools when the task is finding patterns in a mass of data.

Introduction

Monitoring the state of a complex system requires much more than just following the changes of individual parameters over time. To understand and control a complex system it is necessary to understand the configural relationship between several variables, a difficult task. Whether it's effectively getting a small car across town, keeping a nuclear plant within safe bounds, or managing a patient in an ICU, complex systems require monitoring and control based on relationships between variables rather than on any one variable alone. A speed appropriate to driving that small car straight down the block becomes inappropriate when the steering wheel is turned hard to go around a corner, because the meaning of the value of the parameter *speed* depends on the state of the variable *direction* and its derivative *change* of direction. Finding new methods such as graphs to represent the configural state of the complex dynamic of an ICU patient with associated technical support equipment has been advocated for many years [1–5], and indeed previous research suggests good reasons to believe that finding the right way to represent a data set can lead to substantial improvements in human understanding and control of real time systems [6–8].

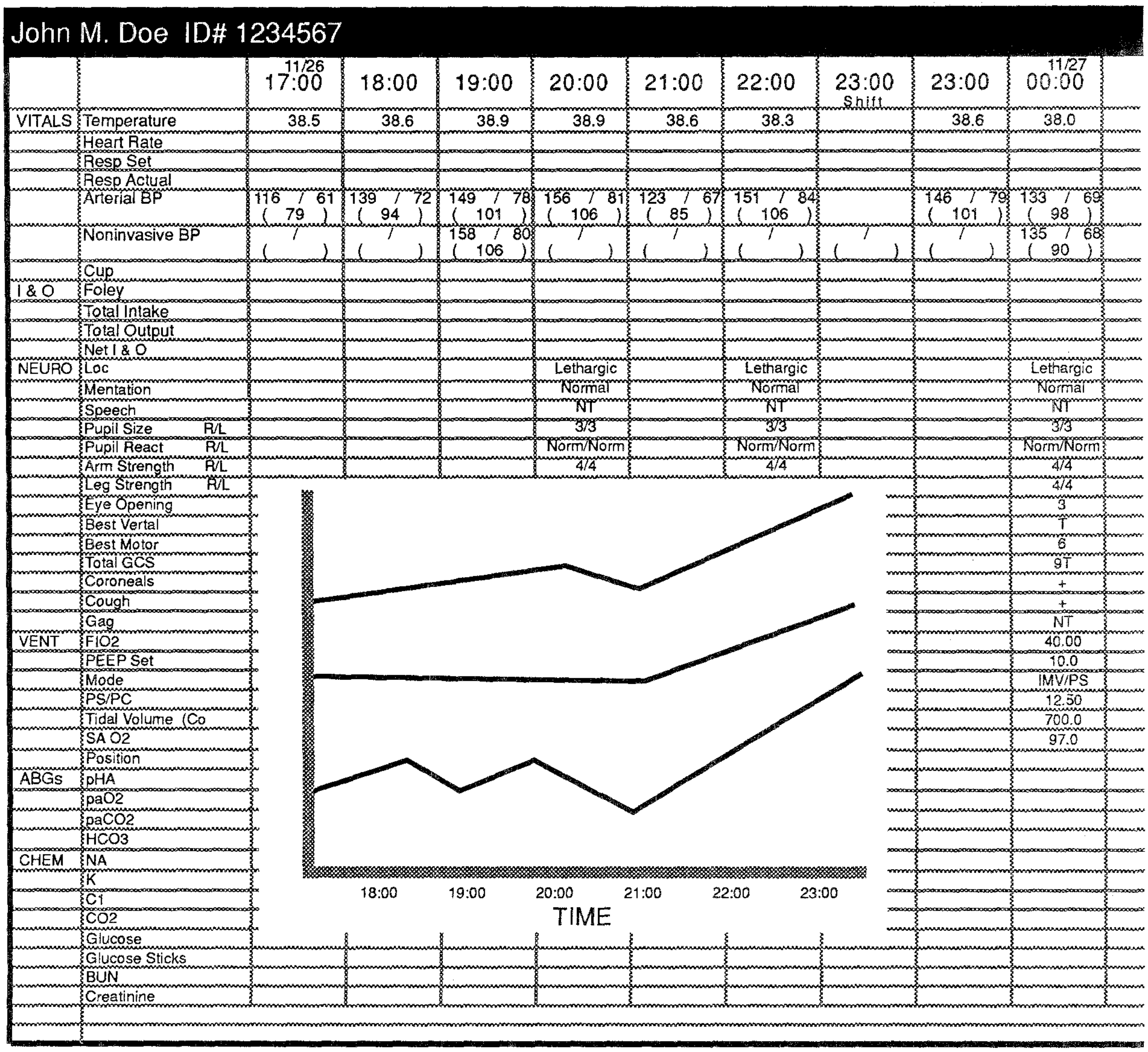
Reviews of the literature on statistical graphics, however, show that standard graphics such as line graphs or bar charts aid understanding only some of the time, for some tasks and for some people. According to the most comprehensive review [9], there are about as many research studies finding that people perform a task better with tables of numbers than with graphs as the reverse. Outnumbering either of these two findings is the most common finding of all: that performance using graphs is about the same as performance using tables of numbers. Since tables of numbers are often much easier to create and manipulate on a computer screen, it would be easy to conclude that graphs are usually not worth the effort. This would be an erroneous conclusion. There's more to human information processing of visual displays than standard statistical charts make use of, and finding more appropriate forms of graphic display could lead to improved human understanding and control. This paper will present such an alternative graphic system and explain its cognitive justification.

An information processing view of the ICU environment. A patient is typically in an intensive care unit because the physiological processes which normally maintain the balance of essential functions in the body have temporarily lost their ability to do so. Medical personnel use monitoring procedures and therapeutic interventions in an effort to restore and then maintain the integrity of these processes. Choice of therapeutic intervention is based on interpretation of the results of the monitoring procedures, but this interpretation involves more than simply tracking the value of any one variable because the meaning of a finding depends upon the full context within which that finding occurs. 'Context', as used here, really means two different things. First, as in steering a car around a corner, at any given moment the meaning of one ICU monitoring parameter depends upon the state of one or more other such parameters. Second, the meaning of a parameter at any given moment often does not lie within the current moment alone, but rather is derived in part from what has been going on in the past, especially the recent past. We need to know whether the patient is progressing from the original undesirable state to be a better one, and, if not, we need to know enough about the state to know how to rectify the situation. This process involves the integration of large amounts of data, since the state of the patient at any single time consists of a large number of variables, and these states are multiplied across time.

Integration is a slippery word, however. It often is used to mean little more than bringing together in a single location data from several sources, but the level of integration of data required to effectively control a complex system goes far beyond this. If we take two monitoring devices, say a ventilator and capnometer, and run cables from them to a common display device so that the data from both monitors can appear on a single screen, we might say that we've achieved integration of this data. In fact, all we've achieved is *aggregation.* Integration of data in an ICU can take place either within a closed loop machine system that attempts to automatically control one or more therapeutic devices based on changing values of incoming parameters, or else – far more commonly – within the head of a person who must decide what action to take. Still, aggregating data together in a single location is an important first step toward human integration of that data, and over the years support for aggregation has blossomed.

Aggregation via tables of numbers. Since the human capacity for accurately remembering large amounts of detailed information is very limited, we usually rely on an external memory aid to store the data so we can refer to them later as needed, to help us search for patterns in part of a current data set without losing track of other parts of that set, and so that others can refer to these data in our absence. In the case of ICU data, this is normally achieved by means of a bedside flowsheet, or possibly a computerized version of one, as in Fig. 1.

This figure illustrates key aspects of the ICU data integration process. The computer that generates this display must have access to multiple sources of data, either through automated online data collection or through entry by a human. In this way it serves as an aggregation device. As soon as data are aggregated, the data must – if humans are to make decisions based on that data – be presented in some format for people to view. In the present figure, the format chosen was a virtual duplication of the classic flowsheet format. Once data have been aggre-



John M. Doe ID# 1234567

		11/26 17:00	18:00	19:00	20:00	21:00	22:00	23:00 Shift	23:00	11/27 00:00
VITALS	Temperature	38.5	38.6	38.9	38.9	38.6	38.3		38.6	38.0
	Heart Rate									
	Resp Set									
	Resp Actual									
	Arterial BP	116 / 61 (79)	139 / 72 (94)	149 / 78 (101)	156 / 81 (106)	123 / 67 (85)	151 / 84 (106)		146 / 79 (101)	133 / 69 (98)
	Noninvasive BP	/ ( )	/ ( )	158 / 80 (106)	/ ( )	/ ( )	/ ( )	/ ( )	/ ( )	135 / 68 (90)
	Cup									
I & O	Foley									
	Total Intake									
	Total Output									
	Net I & O									
NEURO	Loc				Lethargic		Lethargic			Lethargic
	Mentation				Normal		Normal			Normal
	Speech				NT		NT			NT
	Pupil Size R/L				3/3		3/3			3/3
	Pupil React R/L				Norm/Norm		Norm/Norm			Norm/Norm
	Arm Strength R/L				4/4		4/4			4/4
	Leg Strength R/L									4/4
	Eye Opening									3
	Best Vertal									T
	Best Motor									6
	Total GCS									9T
	Coroneals									+
	Cough									+
	Gag									NT
VENT	FIO2									40.00
	PEEP Set									10.0
	Mode									IMV/PS
	PS/PC									12.50
	Tidal Volume (Co									700.0
	SA O2									97.0
	Position									
ABGs	pHA									
	paO2									
	paCO2									
	HCO3									
CHEM	NA									
	K									
	C1									
	CO2									
	Glucose									
	Glucose Sticks									
	BUN									
	Creatinine									

Fig. 1. The single most typical data display in computer workstations attempting to support integration of ICU data. A tabular display, meant to emulate the traditional paper flowsheet, contains numbers representing the state of many patient and technology variables. Each column of the table represents an hour of time. The line graph plots a subset of the variables over a subset of time.

gated and formatted into a tabular arrangement, it immediately becomes clear that assistance with making sense of numbers would be a boon. There are two fundamental approaches to providing such assistance. First, there are a small but growing number of 'intelligent' systems that attempt to alert the user to significant events, or perhaps to suggest what the events mean and how they should be dealt with. Second, there are a variety of ways in which the numerical table can be augmented or replaced with an alternative representation of the data, a different view, a new perspective. This second approach contrasts with the intelligent systems approach by leaving decisions about which events are significant, what they mean, and how to react to them all within the head of the user. Display of a line graph of a selected set of the variables contained in the data table is by far the most common approach to providing an aid to interpretation of ICU data, and for that reason it is worth taking a

	Ventilator		Patient	
Epoch	Set Rate	Set Volume	Spont Rate	Spont Volume
1	12	0.50	0	0.00
2	12	0.50	0	0.00
3	12	0.50	0	0.00
4	10	0.50	3	0.50
5	10	0.50	5	0.50
6	10	0.50	10	0.10
7	10	0.50	8	0.15
8	8	0.50	8	0.30
9	6	0.50	8	0.40
10	4	0.50	12	0.40
11	3	0.50	12	0.42
12	3	0.50	12	0.42

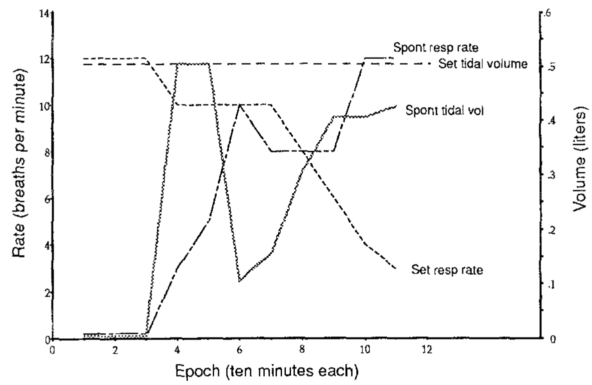


Fig. 2. Four ventilator variables recorded for 12 epochs of ten minutes each, shown first as a table of numbers and then as a line graph. The line graph may help the reader see more quickly the overall pattern of data, or it may not. Previous research has found line graphs sometimes improve decisions, but it is hard to predict when and under what conditions.

moment to consider how a line graph might improve on a table of numbers.

Mental integration of data supported by line graph displays. An example will illustrate how a line graph is intended to help in mental integration of ICU data. The left frame of Fig. 2 shows a simplified version of a mechanical ventilation situation, 12 epochs of data (each summarizing ten minutes of time, thus 12 epochs = 120 minutes) in which rate and tidal volume of a ventilator is shown in the left two columns and the patient's own spontaneous rate and volume are shown in the right two columns. The right frame of Fig. 2 shows the same data, but presented as a line graph.

If the line graph helps make these data more informative, it does so by virtue of at least two factors. First, data that previously were linguistic are now visual. The human brain has substantial neural tissue devoted to processing visual patterns which means that presenting the line graph in addition to the table of numbers should increase the chances that a person will spot some pattern or anomaly if such pattern or anomaly does exist, because there is now more human information processing capacity that can act on the data. Visual as well as verbal capacity is put to work and there should be at least some occasions on which the visual processing system will spot something the verbal one did not. Second, even if the line graph were presented without the accompanying table, it still might lead to better performance as long as the task were of a certain type. In the literature review cited above [9], the type of task a subject was performing was correlated with whether table or graph better supported performance. Line graphs are more likely to be an improvement over tables when the task is to spot some trend or other pattern.

Line graphs: display of many variables leads to difficulties. Line graphs, however, are far from a perfect aid to integration, even when the integration is nothing more than spotting some simple pattern. There are at least two limitations on line graphs for pattern recognition: the number of classes of data that can be shown on one graph and the visual confusion that results when more than just a few lines are placed on a graph. Suppose we wished to represent a set of ICU data more realistic than just the four lines shown in Fig. 2. We are after all collecting many variables with our ICU equipment and we have them available in electronic form ready to be interpreted. What happens when we try to plot them? For example, suppose we wished to add fraction of inspired oxygen (FIO2) to our data display. Where would it go? There is no place remaining on the graph to place a new vertical axis labeled 'FIO2', since one end already has the scale for rate and the other end has the scale for volume. In general, a single line graph will not be able to comfortably accommodate more than two scales at a time, and if we wish to plot even as few as three variables that do not share common scales, we might have to go to multiple line graphs stacked one above another or laid out as a series of graphs

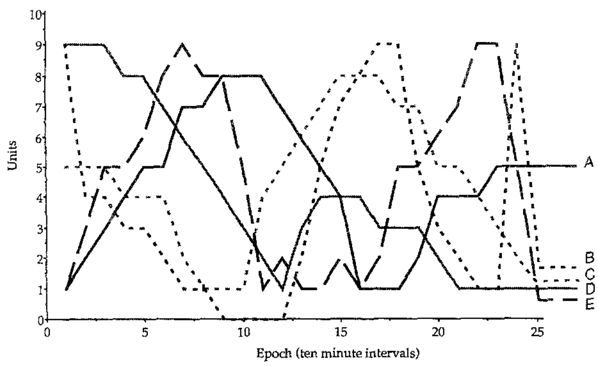


Fig. 3. Five variables across 25 epochs of ten minutes each. One of these variables is an exact mirror image of one other, with identical values but in reverse order. This results in a high negative correlation (– 0.69), which one would hope to be able to discover by viewing the graph. Even though there are only five lines here, it is very difficult to find the mirrored pair. It is difficult to use line graphs to represent configurations of variation among several variables.

in a row, in which case a great deal of the advantage of a line graph (specifically, that it brings several channels of data together in a single visual space) disappears. Strictly speaking, it would also be possible to use a single line graph but add more and more vertical axes adjacent to one another on the left and right hand sides of the graph, but this solution is in practice so unappealing as to virtually never be applied.

Furthermore, even in a graph as simple as Fig. 2 it is possible to detect the beginnings of one of the deep problems inherent in line graphs. Even if we could plot all our variables in one physical space, how easy is it at a glance to both keep separate yet mentally integrate the lines rising and falling across the graph? Visual confusion of overlapping similar lines is a problem [10], one that gets worse as more variables are added. Consider Fig. 3, in which five variables labeled A through E are graphed, over 25 epochs of ten minutes each. Two of these five lines are the same sequence of numbers, one forward and one backward, but how easy is it to find these closely related trends? Integration of many variables, not a few, is what we need to monitor a complex systems but when graphic displays become visual spaghetti it is not possible to integrate these variables together into a meaningful configuration.[1]

Unless it is exceptionally cleverly designed, one line graph cannot easily accomodate more than two scales or more than a few lines. These are two important and deep problems with line graphs, not simply minor points of criticism. There are ways of dealing with these problems – such as creating multiple line graphs when multiple scales are needed and adding color or other distinctive attributes to individual lines when many lines are plotted – but these fixes are of limited usefulness and do not address the fundamental problem with line graphs. This 'problem' is in fact both the great weakness and the great strength of line graphs. They are arbitrary.

Arbitrary vs. metaphor graphics. Imagine for a moment a ventilator and patient connected in an ICU. The four critical variables of the ventilation example are really quite distinct when standing by the bedside. It's easy for an observer standing in the ICU to keep separate what the ventilator is doing from what the patient is doing and it is just as easy to distinguish increases in rate of breathing from increases in amount of air carried on a single breath. The four variables in the real world are quite distinct from one another, but look at the way these variables get represented in the line graph. Each becomes nothing more than a line that rises and falls as it moves across the x axis, and higher rates look exactly like larger tidal volumes. The problem here is that everything looks alike in a line graph and all line graphs look alike.

Line graphs are one example of a class of statistical graphics that can be termed *arbitrary graphics* or *universal graphics*. These representations, such as bar charts, pie charts, and line graphs, are useful for any type of data that comes in as numbers. In this respect they are universal. But the way they achieve that universality is by reducing the multifold richness of the physical world to a single graphic convention. In the case of line graphs the convention is simply, 'As the numbers get bigger, make the line move upwards a corresponding amount.'

[1] Appendix A contains this graph with only the two related lines showing, with the three distracting lines removed.

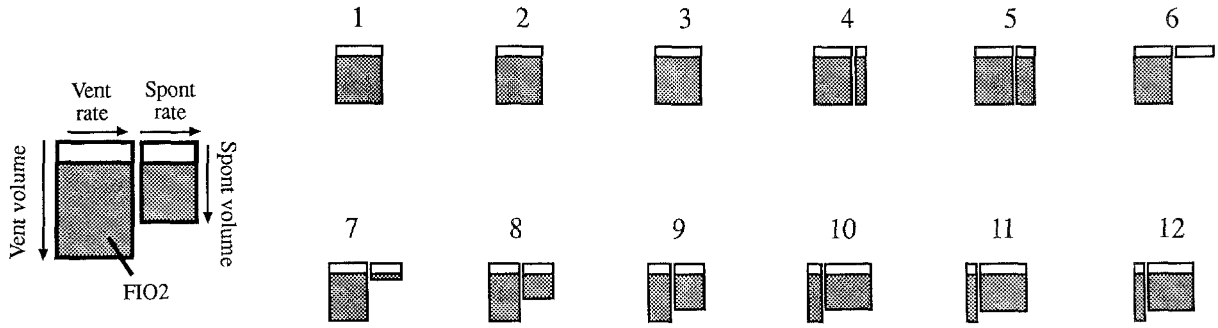


Fig. 4. Volume rectangle representation of the data shown above in Fig. 2 as a table of numbers and as a line graph. Twelve epochs of time are summarized in twelve frames. In each frame is room for two rectangles to appear, one for the ventilator and one for the patient. Rectangles are drawn from the top downward, with greater tidal volume represented by deeper rectangles. Wider rectangles correspond to more rapid rate. The shaded region shows alveolar space with degree of shading corresponding to FIO2, which does not change here. The narrow white band at the top of each rectangle represents this patient's dead space.

Universality of application does not imply that a graphic will be good for decision support. Quite the contrary. To the degree that a graphic is universal, it will tend to squash all the rich variability of the natural world down into a tightly restricted visual appearance. It may be that if we could find an alternative visual representation of data, a display method that was less arbitrary than standard statistical graphs, we might find that such a representation fits better with human judgment and decision making capabilities and thus would be superior as a support for monitoring and control. One alternative to arbitrary/universal graphics is a *metaphor graphic* [11–13] and we have created a metaphor graphic that may meet these criteria, at least for the respiratory therapy section of the ICU flowsheet.

Volume rectangles: a metaphor graphic for respiratory data

Figure 4 shows the same ventilation data as shown in Fig. 2, but in a representation that is uniquely tailored for respiratory data. These *volume rectangles* depict the 12 epochs of data as 12 frames on a blank background. The key to understanding them is in three parts. First, within each frame there is room for two rectangles: a ventilator rectangle on the left and a patient rectangle on the right. If only one rectangle is shown, it will always be the ventilator alone, since it is through this device that we acquire the data. Second, within any frame, the ventilator and the patient each have two key parameters that can be represented by the two sides of their respective rectangles: how many tides of air were exchanged (rate), and the average volume of each of these tides (tidal volume). These are represented by the two sides of a rectangle, such that as a parameter increases, the corresponding side gets longer.

The sides of the rectangle are not assigned arbitrarily. Rather, a metaphoric mapping, an analogue is created. A deeper breath is one that penetrates farther down into the lungs, so we represent a deeper tide as a deeper rectangle. (Note that the rectangle is drawn starting at the top and extending some variable amount downward, not drawn starting at the base then extending a variable amount upward.) Rate of breathing is represented by the total width of the rectangle. Recall that this rectangle represents many breaths over a ten minute epoch. Each breath within that epoch can be imagined as a single very narrow rectangle. The more of these breaths that come in a given epoch, the wider the total rectangle gets as we stack each single breath 'slice' alongside the others, yielding a very wide total rectangle if there are very many tides and a relatively narrow total rectangle if there are relatively few tides. Faster rate = wider rectangles. Deeper breaths = deeper rectangles.

Area of the rectangle is both of interest in itself and also serves as a place to code further information. Minute volume is easily seen as total area within the rectangle. Furthermore, it is easy to

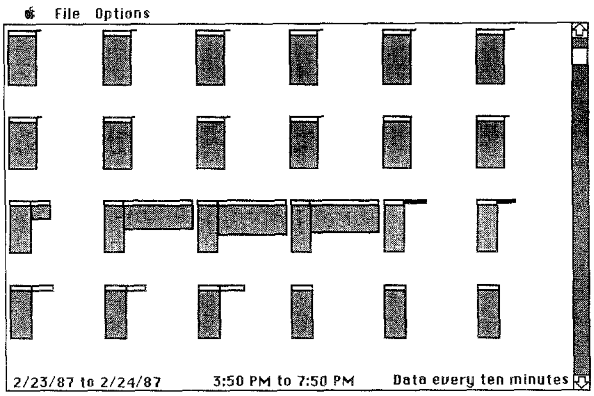


Fig. 5. Four hours of data from an actual patient. This is the basic level view provided by the volume rectangle computer system when the user is restricted to a small screen. From this view it is possible to scroll forward or backwards in time or to zoom out to get a broad overview (see Fig. 7) or in to see the actual numbers underlying these rectangles (see Fig. 6). A user with a workstation sized screen could see many more hours of data than this.

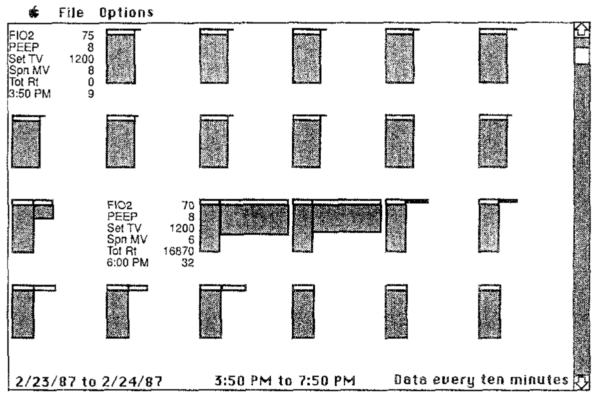


Fig. 6. Four hours of data from an actual patient. Two of the frames have been clicked on with the mouse and have changed from iconic into numerical form. Clicking again on either of these would turn it back into an icon once more. A menu item under 'Options' will turn the entire screen into frames of numbers if the user wishes. This figure illustrates that the user always has the actual digital values ready at hand. The icons are not intended to replace numbers but to complement them.

represent the distinction between dead space and alveolar space in such a graphic. The alveolar space is shaded, both to provide a way of encoding gas information such as FIO2, and also to distinguish it from dead space, which is left unshaded. A breath with volume so shallow as to not reach the alveolae would appear as a rectangle so shallow as to not reach down to the level where shading begins, as in patient rectangle of frame 6 of Fig. 4.

Figure 4 should be interpretable to the reader. In frame one, there is only one rectangle, representing the ventilator alone, with the patient contributing nothing spontaneously. Frames one through three show no change over thirty minutes. In frame four, however, the patient begins to contribute some spontaneous breathing but the narrowness of the rectangle tells us that rate was slow: an average of about three breaths per minute. In frame five the depth of patient tides is holding steady and rate is improving. In frame six, however, the patient breathes very rapidly but with such shallowness that there is no alveolar exchange. In frames seven through ten we see good rate and improving depth, so much so that the ventilator is being cut back. In frames 10–12 we have a patient who has taken over his own breathing again, with only minor assistance from the ventilator.

Review the big picture again. With just glance at the graphic the general course of events very quickly becomes apparent. There is no need to translate between numbers and their real world implications. The metaphoric graphic in a sense accomplished this step by presenting the data in a way that 'looks like' the original situation. You can look at the graphics as though you were viewing the world, because the graphic was carefully designed to act as a visual metaphor.

Compare the interpretability of Figs 2 and 4, showing the same data as line and metaphor graphics. Figure 5 shows a far more complex situation, data taken from an actual patient in the surgical intensive care unit at Palo Alto VA Medical Center. Each row shows six 10 minute frames, thus one hour of data. The total image shown is the size of the smallest Macintosh computer screen.

Since this is a computerized representational system, the user is not restricted to a single image. The user can scroll downward in the data using the increasingly familiar scroll bar on the right, either scrolling one line at a time (one hour) or one page at a time (four hours). In this way, many hours of data can be reviewed within a few seconds. Furthermore, this basic level display is only one way the data may be viewed. The user may look more

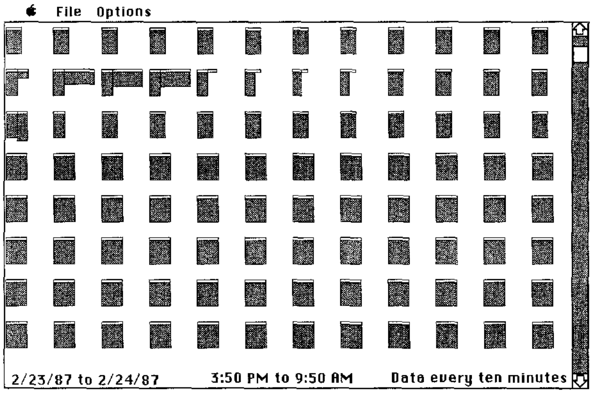


Fig. 7. Sixteen hours of data, the view presented when a user chooses to zoom out. Each frame is still ten minutes but now there are 12 frames per line (two hours) and nine lines. The four hours of data that previously (Figs 5 and 6) took an entire screen now fill only the top two rows. By scrolling forward a page at a time, the user quickly moves through 18 hour chunks of data, and thus discovers where in the data to devote valuable time, energy, and attention.

closely at all or part of the data (zoom in) or may look in less detail at a larger subset of the data (zoom out).

Figure 6 shows the effect of asking for details on two frames (the user has mouse-clicked on these two frames). The data previously displayed as icons now are displayed as exact values. If the user had desired, simply selecting an option from the menu at screen's top would turn all frames currently on the screen into numbers. In other words, at all times the underlying numbers are available to the user; all it takes is a gesture to cause whichever numbers are of interest to appear. It is important to note that this graphic approach is not intended to replace numbers but no augment them, following the finding that some tasks seem to cry out for graphical displays while other tasks seem to be better supported by tables of numbers [9].

Figure 7 shows what happens when a user chooses to 'zoom out'. Each frame still represents ten minutes but now there are 12 frames per line (two hours) and 8 lines, for a total representation of 16 hours of data, again assuming only the smallest Macintosh screen. All of the data shown in Fig. 5 above now appear in the upper two rows of Fig. 7. Scrolling is possible in two hour (one line) and 16 hour (one page) increments. When it becomes clear which portion of the data deserves further attention, the user need only click on that area to zoom back in. A basic level view as in Fig. 5 instantly replaces the distant overview, and another mouse click will take the user down to the level of numerical detail if that is desired.

How is such a system to be used? Consider an attending physician taking over management of an unfamiliar patient. First, a rapid overview with 16 hours of data per screen (Fig. 7) would reveal whether the past many hours had been relatively uneventful or whether significant changes in status had occurred. If interesting changes appear in an overall pattern of a relatively steady state, zooming in to the basic level view of four hours represented as large icons might be useful to see details of the icons (Fig. 5). If any doubts remain about what happened and how, either the entire screen could be turned into a table of numbers or else the one or two frames where the changes of interest occurred could be transformed into numbers (Fig. 6). Total time to accomplish all of this would be less than the time taken to read this paragraph. Pilot research we have conducted suggests the actions would require essentially no training, no manual, no recall of keywords or commands. The user would simply scroll and click, naturally and quickly.

Discussion

The ICU is a data rich environment. Many people believe that graphic representation is a great aid to comprehension of data and that it will allow people to spot patterns in an otherwise unmanageable mass of data. Unfortunately, careful research does not support this as an unqualified generalization. Graphic representation helps some people, some of the time, for some tasks and with some kinds of data. The present research seeks both to improve our knowledge of factors that influence the probability a graphic will help and also to develop a useful tool for patient care. The factor under investigation here is the degree to which a graphic is metaphoric rather than arbitrary. The graphic system introduced here, called volume rectangles, aims to represent respiratory data in a way that looks like the real world situation, but not in a literal sense of 'looks like'.

Line graphs have here been contrasted with metaphor graphs and the strengths and weaknesses of each have been briefly explored. Line graphs are universally applicable because they are arbitrary. They thus are easy to create for ICU data of any sort. However, they are not always interpretable when the number of lines being displayed grows beyond a very small number or when several parameters not sharing common scales must be examined. Temporal trend of one or two variables is, however, something line graphs are very good at displaying. Because trend over the recent past is a very important concern for ICU management, line graphs have a significant place there and the present research should not be taken as a call for the elimination of them.

Volume rectangles, which might improve upon the informational value of line graphs much as line graphs improve upon the informational value of tables, also can be used to display changes over time but they do so in a way that allows decision making to be based on understanding configural changes in many parameters rather than simple changes in one or two. Displaying many variables at once is a primary strength of the metaphor graphics approach, and we are presently extending these relatively simple volume rectangles into a much more complex representation, with variables such as mean airway pressure, inspired to expired ratio, positive end expiratory pressure (PEEP), and ventilation mode being represented in a unified icon. Keeping track of eight variables on a single line graph may be very difficult, but a good metaphor graphic will permit display of eight or even more at one time simply because variables are now distinctive in the graphic world just as they are in the real world. Furthermore, the metaphor graphic approach is easily adaptable to displays that are not time based, such as simultaneous display of the current state of the vital parameters of many different patients on a ward.

The advantages of such an approach are substantial. First, visual pattern recognition is a powerful human ability. It occurs with little sense of strain or effort and it can proceed even when a verbal memory load (e.g. a phone number) is being held in short term memory [15]. Second, in many data sets, the bulk of the data is of little interest, yet if the data is in numerical form it must be carefully scanned in order to discover which small fraction is the part of interest. With volume rectangles, valuable human resources are not wasted looking through numbers that vary in trivial ways. Volume rectangles make the significant apparent. The user rapidly homes in on the critical part of the data. Finally, when a clinical worker is fatigued or distracted, review of data presented in a visual format may improve confidence that the essence of the situation is correctly understood and that it is unlikely that a critical numerical value has been overlooked or misinterpreted. Human performance research is needed to verify that this is the case.

Extensions and evaluation of the approach. The icons shown in this article are only a beginning. The point to the present research is not that the exact representation shown here is optimal for respiratory monitoring, but rather that the metaphor graphics approach to representation of data can make a suprisingly large amount of data clearly informative. Along these lines it should be noted that the present approach is not only more general than the few variables graphed here, but more general than respiratory monitoring, even more general than medical information science. Related research [12–14] has developed metaphoric displays for Bayesian diagnostic reasoning and for display of a clinical database and the method can be extended into representation of commercial, financial, or industrial data. Preliminary experiments evaluating the Bayesian and database computer systems suggests that metaphor graphic representation consistently leads to decisions that are as accurate as decisions based on tables of numbers, but that are much faster than number based decisions. Such an evaluation of the present respiratory volume rectangles, looking both at acceptability of the system to ICU staff and at measurable effects of the system on human performance, is in progress and will be reported in a subsequent paper.

Acknowledgements

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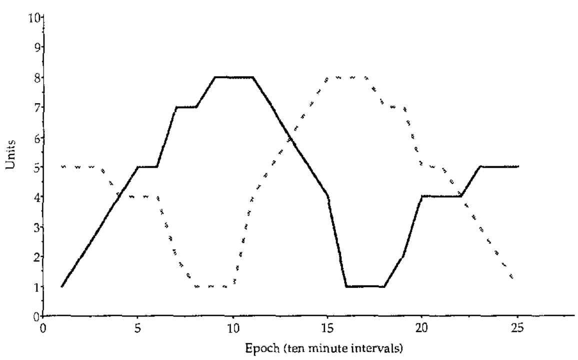
Appendix A

Solution to the puzzle of Fig. 3, in which two variables out of five are related by being the same sequence of numbers, one forward and one reversed. This figure is identical to Fig. 3 except that three lines have been removed.



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