# Visualization of large datasets in intensive care

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## ABSTRACT

*At the "Institut für Anaesthesiologie der Ludwig–Maximilians–Universität" in Munich a computer–based system for the analysis and interpretation of renal function and fluid and electrolyte metabolism of critical care patients has been developed. This paper describes requirements and implementation aspects of the presentation of data to the physician. Key issue is, how to transform the enormous—and, as we all know, constantly increasing—amount of plain data available in modern intensive care units (ICUs) into relevant information which can be easily turned into therapeutic actions. These issues have been discussed in literature extensively over many years, but with the upcoming of moderately priced, though powerful graphical UNIX workstations an extended functionality is feasible.*

## INTRODUCTION

Monitoring of laboratory data of critical patients in intensive care is an important means of improvement of care and avoidance of complications. Especially monitoring of data referring to renal function, fluid and electrolyte metabolism has turned out to be very useful in this aspect. In the *Institut für Anaesthesiologie der Ludwig–Maximilians–Universität* in Munich this monitoring proves its value since more than ten years [4].

As a sheet of printed paper, laboratory data derived from the patients blood and urine material is available on ward normally around noon once a day. This piece of paper collects 61 plain numeric values plus five patient related data and is shown in figure 1.

Even at a glimpse it is obvious, that this presentation of data suffers from some disadvantages:

1. The *interpretation* of the laboratory data is normally based on the expertise of an experienced physician in this field. It requires a subtle and thorough knowledge of the complex interactions in the kidneys and the water and electrolyte metabolism to interpret the data, transform them into a diagnosis and finally into therapeutic actions.

2. Every day 61 plain numeric values have to be scrutinized for *every* patient on ward. In our case, 22 patients are possible, summing up to the enormous amount of 1342 values *every day.*

3. Since the sheets of paper are processed serially by a physician, it is not possible to decide quickly, which patient is critical in the moment and which one is not.

4. Faulty or implausible values may be overseen very easily and may lead to wrong conclusions.

5. All the information has to be forwarded to the medical staff of the next shift.

## REQUIREMENTS

One important issue, which is not directly related to the monitoring process has to be mentioned at first: It turned out to be mandatory, that the monitoring system has *direct access to the laboratory database* and the *patient information database.* Otherwise the consistency and accuracy of data stored in the local database of the monitoring computer cannot be guaranteed. Regarding the presentation of data, the following requirements on a decision support system in the area of renal function are given:

1. Laboratory data—plain numeric values—have to be condensed to a number of *calculated key parameters*, which describe the patient briefly, but correctly regarding his renal function and fluid and electrolyte metabolism. These condensed values have to be transformed into a graphical domain in order to ease the perception by the physician.

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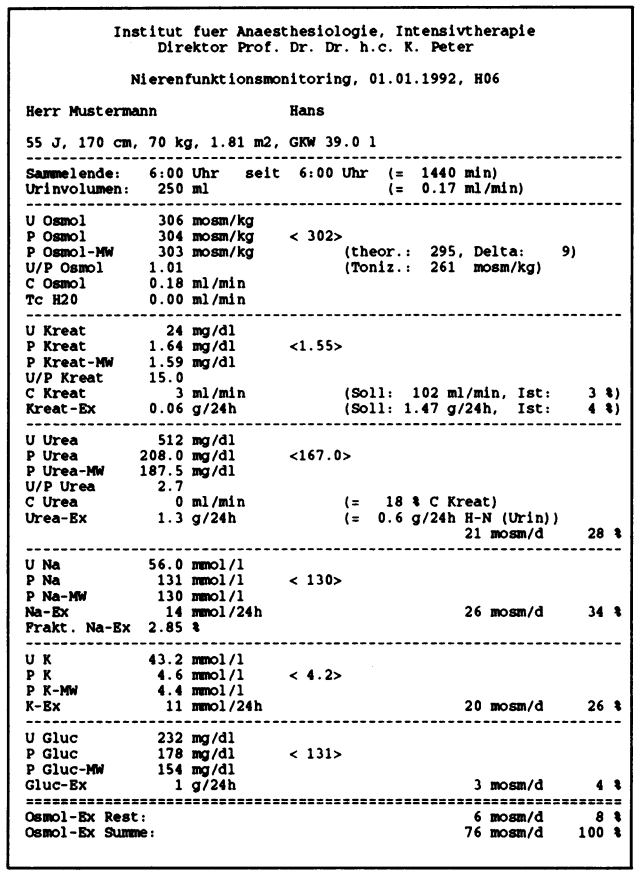

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          Institut fuer Anaesthesiologie, Intensivtherapie
              Direktor Prof. Dr. Dr. h.c. K. Peter

           Nierenfunktionsmonitoring, 01.01.1992, H06

Herr Mustermann                Hans

55 J, 170 cm, 70 kg, 1.81 m2, GKW 39.0 l
-------------------------------------------------------------------
Sammelende:   6:00 Uhr   seit  6:00 Uhr  (=  1440 min)
Urinvolumen:   250 ml                    (=  0.17 ml/min)
-------------------------------------------------------------------
U Osmol        306 mosm/kg
P Osmol        304 mosm/kg    < 302>
P Osmol-MW     303 mosm/kg          (theor.:  295, Delta:    9)
U/P Osmol     1.01                  (Toniz.:  261  mosm/kg)
C Osmol       0.18 ml/min
Tc H20        0.00 ml/min
-------------------------------------------------------------------
U Kreat         24 mg/dl
P Kreat       1.64 mg/dl      <1.55>
P Kreat-MW    1.59 mg/dl
U/P Kreat     15.0
C Kreat          3 ml/min           (Soll:  102 ml/min, Ist:    3 %)
Kreat-Ex      0.06 g/24h            (Soll: 1.47 g/24h,  Ist:    4 %)
-------------------------------------------------------------------
U Urea         512 mg/dl
P Urea       208.0 mg/dl      <167.0>
P Urea-MW    187.5 mg/dl
U/P Urea       2.7
C Urea           0 ml/min           (=   18 % C Kreat)
Urea-Ex        1.3 g/24h            (=  0.6 g/24h H-N (Urin))
                                                 21 mosm/d     28 %
-------------------------------------------------------------------
U Na          56.0 mmol/l
P Na           131 mmol/l     < 130>
P Na-MW        130 mmol/l
Na-Ex           14 mmol/24h                      26 mosm/d     34 %
Frakt. Na-Ex  2.85 %
-------------------------------------------------------------------
U K           43.2 mmol/l
P K            4.6 mmol/l     < 4.2>
P K-MW         4.4 mmol/l
K-Ex            11 mmol/24h                     20 mosm/d     26 %
-------------------------------------------------------------------
U Gluc         232 mg/dl
P Gluc         178 mg/dl      < 131>
P Gluc-MW      154 mg/dl
Gluc-Ex          1 g/24h                        3 mosm/d      4 %
===================================================================
Osmol-Ex Rest:                                  6 mosm/d      8 %
Osmol-Ex Summe:                                76 mosm/d    100 %
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Figure 1: A conventional report

2. After having selected an endangered patient on the basis of these graphical icons, more and detailed information on this patient has to be provided by the computer, such as a history of important physiological values.

3. On request, the computer should provide some hints: Information about the probability of distinct well known complications like acute renal failure (ARF) seems to be useful.

4. If a classification is not possible, a physician might simply want to have a list of current syndromes of the patient in a textual manner. Hints like "the patient shows a severe hypernatriaemia" might be useful for a physician in order to consider further investigations.

## OVERVIEW OVER NIMON

As stated earlier, a computer system called NIMON has been installed on ward to support monitoring of renal function and fluid and electrolyte metabolism of critical ill patients. An overview over the system is given in figure 2. The patients blood and urine material is analyzed in the laboratory and the results are available on ward around noon. The laboratory data and patient related infomation like sex, age and so on is collected by NIMON and stored in a local database. This database also incorporates all strategies, rules and parameters used by higher functional layers as well as all information necessary to customize the system to the needs of particular physicians.

If a physician wants information about one or more patients, she or he enters a request via *Input–Output*, i.e. keyboard, mouse and computer screen in figure 2. The request is processed by the *Request and Display Manager*. This module decides, which further modules should be activated: If it is a global request for a fast visualization of the patients status, the *Visualization Manager* is activated. This component retrieves needed information from the local *Data Base*. In any case, however, the *Knowledge Based Interpretation* module is active, to prevent presentation of corrupted, faulty or inconsistent data to the physician.

In case of a request for detailed information, control is passed directly to the module *Knowledge Based Interpretation*. Here the probabilities for distinct complications like "acute renal failure" are computed (see the description in [7]). Furthermore a list of possible syndromes is provided on request. The output from this module is plain text.

### Basics of the Visualization

Key issue of our work is to *hide* raw numerical data as much as possible from the physician and to transform it into graphical or textual information. This can be achieved by displaying a single metaphoric picture of a patient, which collects all relevant data and by that provides a feeling about this patient to the physician. To achieve this, a transformation of numeric data must take place. In our case, there are three key values, which are sufficient for a first impresssion of the renal function and fluid and electrolyte balance of a patient:

1. The creatinine clearance $C_{Creat}$, a practicable measure for the glomerular filtration, describes the amount of generated primary urine. It is the most important parameter and is divided by the individual nominal value and expressed in %.

2. The ratio of urine–to–plasma osmolality $U/P_{Osmol}$ is next important. It is a measure for the tubular reabsorption or excretion of free water. If this ratio gets 1 or near 1, a critical situation might be given.

3. The sodium excretion $FE_{Na}$ is a parameter, which describes the quality of the tubular transport func-

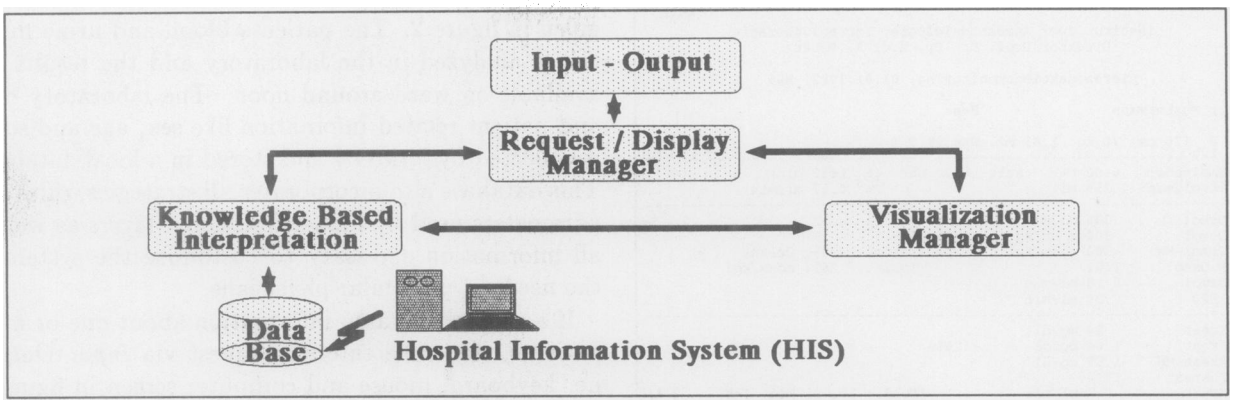


Figure 2: The main components of NIMON

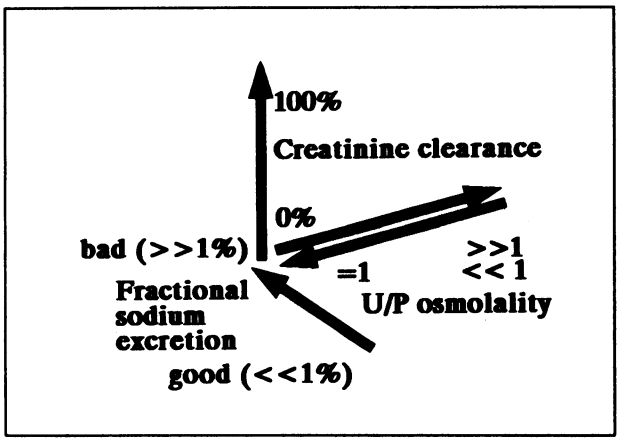


Figure 3: Mapping of the key–values

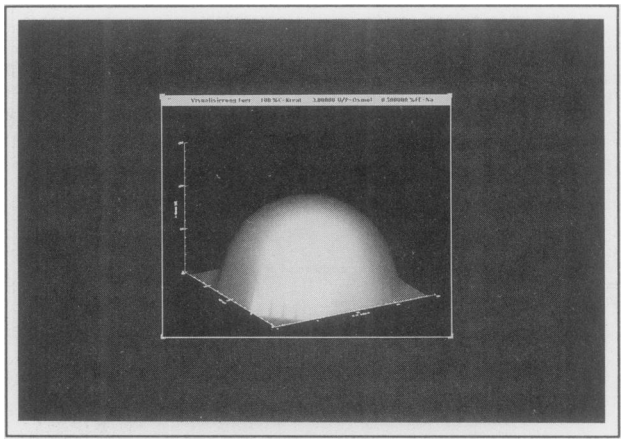

Figure 4: A "normal" patient

tion. The sodium transport is the driving force behind all renal transport– and co–transport mechanisms. Low values (less than 1%) indicate a good function.

If there were more than three values, a different approach would have been taken: By means of methods like fuzzy–set logic or bayesian reasoning algorithms, a transformation of a bigger number of describing values into *one* characterizing figure looks promising.

In our case, a method was searched to display the three key–values in a logical and impressive way. The basic approach is to display a hemisphere, which represents the patients key–values one in each axis. This mapping of the key–values is shown in figure 3.

The most important value is the creatinine clearance $C_{Creat}$ in percent of the nominal value. This value is mapped into the vertical axis to enable a "squeezing" of the figure in case of a reduced $C_{Creat}$. The U/P osmolality $U/P_{Osmol}$ is displayed in the horizontal axis. The displayed value is—like all other displayed values too—calculated in a nonlinear manner: If the value of $U/P_{Osmol}$ is *either* high or low, the figure has a broad basis, since the tubular part of the kidney works and generates hypertonic or hypotonic urine. The more this value approaches the value of "1", the smaller the basis gets and signals possible complications. The fractional sodium excretion $FE_{Na}$ is mapped into the Z–Axis.

A perfectly well patient is represented by a symmetric hemisphere with a relative size of (1,1,1), where the "1's" are derived from the specific nominal values of the patient. Any deviation from the symmetrical shape is signaling, that the patient has complications in distinct aspects. The visualization of such a "normal" patient is provided in figure 4.

An important question is the *scaling* of the figure i.e. what value of a parameter will yield what size of the figure. Since there is no mathematical method to build up dependencies between patients data and problems on the one side and the physicians "feelings" on

the other side, several physicians were asked to express their feelings when looking at selected figures. After that, the actual patients data were presented and, as a result of discussions, the size and shape of the figures fine tuned. "Result" in table 1 shows the relative size of the displayed figure in the related axis.

| Parameter | Value | Result |
|---|---|---|
| **C-Creat** | 0–150% | 0–150% |
| (% nom.) | >150% | Error |
| **U/P-Osmol** | <0,15 | Error |
| | 0,15–0,5 | 1,0 |
| | 0,5–0,65 | 0,9 |
| | 0,65–0,8 | 0,8 |
| | 0,8–0,9 | 0,5 |
| | 0,9–1,1 | 0,1 |
| | 1,1–1,2 | 0,5 |
| | 1,2–1,5 | 0,66 |
| | 1,5–2,0 | 0,9 |
| | 2,0–5,0 | 1,0 |
| | >5,0 | Error |
| **FE-Na** | 0%–1,0% | 1,0 |
| | 1,0%–1,5% | 0,6 |
| | 1,5%–2,0% | 0,4 |
| | 2,0%–5,0% | 0,2 |
| | 5,0%–30,0% | 0,1 |
| | >30% | Error |

Table 1: Transformation of data

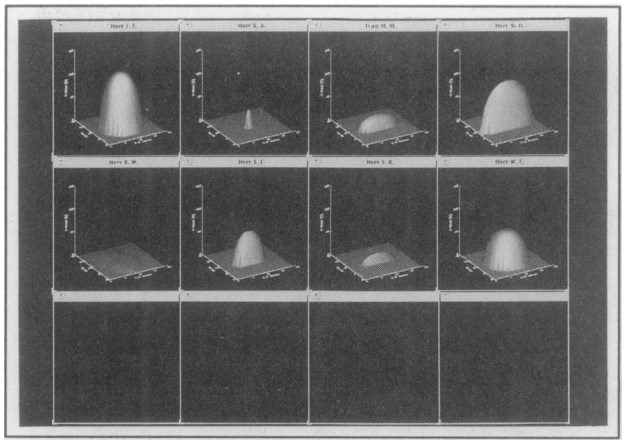

Figure 5: Main selection screen

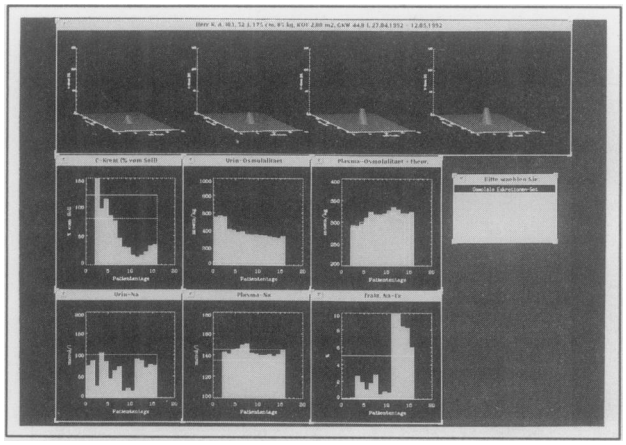

Figure 6: Detailed information screen

## EXAMPLES

In the following, a sample session is presented illustrated by five screen photographies. A startup screen (not shown) checks for permission to start NIMON and displays an option menu. In the daily routine, the first item ("Routine") is normally selected, but NIMON supports also a selection of patients upon arbitrary criteria in order to aid clinical research. The next screen is most important: An overview over all 22 patients is provided on one or two successive screens, depending on the number of patients on ward who are being supervised by NIMON. In the example in figure 5 only 8 patients were present on that day. It seems easy to understand, that last patient "looks fairly good", but the second patient (K.A.) seems to have problems. Patient R.W. (row 2, column 1) looks even worse, since his glomerular filtration is nearly disabled. Selecting a patient simply by clicking on the computer-mouse brings up the next screen: Figure 6 shows all relevant data in a less abstract way, yet still graphical. The windows located in the top row show the history of the patient in the last four days, where the rightmost figure is that one of "today". The idea behind is, that a physician may interpolate, what may come "tomorrow". In this example, the glomerular filtration seems to recover.

More information can be obtained interactively by selecting items like $T_{cH2O}$ and a window with the history of that value will pop up (figure 7). All information stored in the local database is available.

Two more levels of information are implemented: We still can "go down" to the numerical level of data, as shown in figure 8. But this report is not the same as the one presented in figure 1, since possibly erratic values (laboratory errors, measurement failures on ward...) are marked in "red". Furthermore, a check for implausible *combinations* of data is performed.

On request, a physician can get some hints and an textual interpretation of the patients data from NIMON, as shown in figure 9. More on these issues is included in [7].

## DISCUSSION

Use of graphics is known as a powerful means of representing data. As a result, numerous approaches

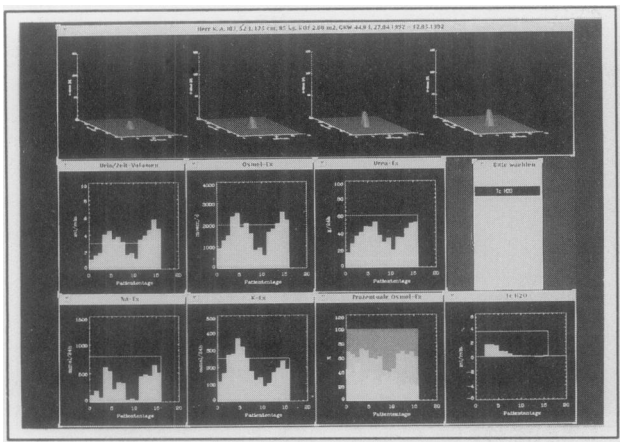

Figure 7: Customized display facility

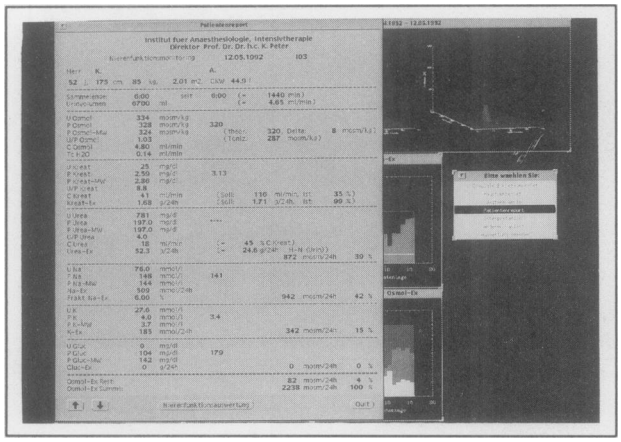

Figure 8: Numeric data feature

are existing. One approach is, to represent information in the shape of a "wheel and spoke" type of diagram, where the distance from the center expresses the likelihood of the corresponding diagnosis (e.g. R. Pionkowski et. al.). However, this requires a reliable expert system in the background, which really does the work. In [3] a special graphical representation, metaphor graphics, is described which leaves more intellectual work at the side of the staff. Use of metaphor graphics turned out to be as accurate as reading data from tables, but faster by a factor of approximately two. In the case of NIMON, the reduction of time needed to recognize an endangered patient is even better, despite of the fact, that more complex information is to be transferred. One reason for this is a refined graphical representation on the basis of a powerful but, of course, more expensive UNIX graphics workstation.

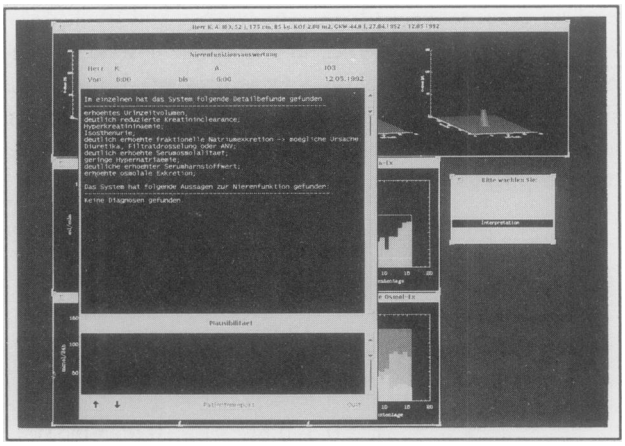

Figure 9: Interpretation feature

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