DESIGNING AN INFORMATION DISPLAY FOR CLINICAL DECISION MAKING IN THE INTENSIVE CARE UNIT

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The Recursive-Diagnostic Framework (RDF) is presented as a way of modelling information in the Intensive Care Unit (ICU). The RDF motivated an exploratory field study of ICU information use, resulting in an ICU information inventory and the definition of 10 design goals. In conjunction with these outputs the RDF also informed the design of a paper prototype. The overall design structure was based on the physiological dimension of the RDF. From the information inventory, elements of situation (the decision dimension of the RDF) were added. Specific design elements were developed, evaluated, and refined iteratively using scenarios based in the data sets of six de-identified patient records. The RDF and the outputs of analysis were useful in determining the overall structure of the design and the grouping of complex decision and physiological data, while the design goals from the exploratory field study assisted in maintaining design priorities and focus.

INTRODUCTION

Miller (2000) and Miller and Sanderson (2000) presented the Recursive Diagnostic Framework (RDF) as a tool for modelling biologically based work domains. Frameworks such as Work Domain Analysis (WDA) (Rasmussen, Pejtersen & Goodstein, 1994; Vicente, 1999) have been successfully used in engineering contexts but many aspects of WDA as it is currently practised may not be appropriate to biologically based systems, even though some use has been explored (Sharp 1996; Hajukiewicz et al, 1998).

Since 2000, Miller has refined the RDF to encompass the fact that that biological systems are intrinsically autonomous, functionally cohesive, independently anticipative and self-organising and apparently stable (Collier & Hooker, 1999). These characteristics are achieved by open far-from-equilibrium gradient dissipative structures (Collier & Hooker, 1999; Schneider & Kay, 1995; Nicolis & Prigogine, 1977) which are of increasing interest to medical research (e.g. Recordati, 2002, 2003). As gradient dissipative structures, biological systems differ from engineered systems in that they are not deterministic and they have no externally imposed reference inputs (Powers, 1978).

In addition, because biological systems are not built, the modes of operation of such systems are incompletely known. Thus from an observer's perspective inner functioning must be inferred by carefully considering input and output relations—that is by 'Black-box' reasoning. Ashby (1956) defines black-box problem solving as reasoning about the functioning of an object whose internal processes are hidden or otherwise inaccessible.

The RDF has two dimensions. The Recursive Hierarchy (RH) models physiology and is based on Beer's (1981) Viable Systems Model (VSM). The VSM postulates the functions that must exist for autonomous viability independently of whether exact mechanisms are known. Thus the VSM is capable of representing black boxes. The VSM is also an information-based model capable of representing biological functioning as sets of dissipative structures which are also information structures (Collier & Hooker, 1999; Nicolis & Prigogine 1977).

The second dimension of the RDF is the Diagnostic Framework (DF) which is based on the elements of situation defined within Klein's (1998) Recognition Primed Decision (RPD) model. In the RDF, the elements of situation represent the information resources in the environment. Clinicians in ICUs use these resources to intervene on ICU patient functioning, based on 'black box' inferences.

When integrated, the RD and DF dimensions form a matrix, where cells are linked by 'if...then' inferential reasoning relations (Ashby, 1956).

RESEARCH PROCESS

From this starting base a research program was defined comprising three phases presented in Table 1. This paper presents phase 2 of this research program. Miller and Sanderson (2003) present the findings of phase 3.

Human error as a motivation for design

Cook, Render and Woods (2000) identified 'gaps' or discontinuities in care (e.g. loss or absence of information), as possible sources of error in medical settings. Xiao and the LOTAS Group (2000) identified artefacts, such as patient records, as important aids in coordinating patient care in emergency departments.

In the ICU, patient care is provided across many days, and across multiple medical and nursing shifts. Artefacts such as patient observation charts are used to support coordination. However, the design of patient information representations, whether electronic or paper-based, has evolved. They have not been systematically designed and may therefore contribute to information gaps and breakdowns in coordination.

Table 1. Phases of RDF based research

Phase	Objective(s)	Activity(ies)	Findings	Outputs
Phase 1 ICU information modelling. Nov 2000 – Aug 2001.	To determine whether the RDF adequately represents conceptualisation frameworks used by medical and nursing staff in ICUs	Video-cued recall interviews (McLennan, Omodei, Rich & Wearing, 1997) involving 8 senior doctors; 17 senior nurses and 5 patients at the Epworth Hospital, Melbourne. Australia.	a) Established the reliability and validity of RDF dimensions as ICU conceptualisation frameworks. b) Defined patterns of physiological and decision information use by medical and nursing staff	1. A model the ICU as an information environment 2. 10 Design goals that summarise the key findings about information use 3. An inventory of ICU information
Phase 2 An ICU Information design Sept 2001 – Mar 2002.	To demonstrate the usefulness of the RDF in information representation design.	1. Collected 10 de-identified patient data sets (Epworth Hospital, Melbourne, Australia). 2. Scenario based design using six of the collected data sets. 3. 3. Data sets were not those of patients included in Phase 1.	a) The RH dimension of the RDF provided an overall structure for design. b) The RDF based information inventory assisted in the design of specific design elements. c) Six patient data could be accommodated within the design framework.	An RDF guided, paper based prototype.
Phase 3 RDF prototype 'proof of principle' evaluation Apr 2002 – June 2003	To evaluate the paper prototype against an existing paper based information representation	Comparative experimental evaluation involving 4 senior doctors and 8 senior nurses (Princess Alexandra Hospital, Brisbane. Australia)	The paper based RDF prototype better supports individual role and common situation awareness	A confirmed 'proof of principle' paper prototype. Recommendations for redesign that will enable further research associated with information artefacts and distributed team coordination.

THE DESIGN PROCESS

Design goals

Ten design goals were defined in Phase 1 as a consequence of exploratory data analysis and statistical testing. The ten design goals were grouped around the following three themes.

1. Represent physiological relationships

This group of goals involved the representation of physiological systems. Some physiological functions have higher priorities in the ICU than others and are attended to more frequently. Physiological functions are also inter-related; these functional relationships need to be made visible. Gradients connections between dissipative processes may each be intervened upon and thus need to be made visible. Finally some physiological processes are known but are not accessible because sensor technology is not available. Inferences about hidden processes also need to be supported.

2. Support 'if...then' reasoning

The second group of design goals is associated with the links between information resources in the ICU environment that are used in decision making and the patient system. A central feature of this group of goals is the 'mutuality' of patient/clinician interaction. Thus it is important that the effects of patient mediated change is as visible in relation to decision elements (eg. diagnoses, goals, effectors), as the effects of clinician actions are on physiological functioning.

Physiological functions also operate within their own time scales and state spaces. Variables need to be representable across possible state spaces which may extend beyond normal state spaces in the critically ill. Time scales also need to be accommodated in design because these determine when we might expect 'if...then' occurrences. Thus it was important that design should make patterns within natural timescales visible.

3. Support professional roles

The third group of design goals were associated with differences between medical and nursing staff in relation to information use. The findings of Phase 1 exploratory data analyses showed that nurses focus tactically on sensed information across a more limited range of physiological functions. Doctors focus strategically on expectations and sensed information across a much broader range of physiological functions. These findings have implications for design evaluation but were not a substantial influence at this stage of the design process.

On the basis of the above goals above it was decided to focus initial design efforts on the structure and grouping of information within an integrated paper based display.

Recursive Hierarchy information structure foundation

The RH is shown in detail in the top four rows of the second table in Figure 1. These rows were 'filled in' in Phase 1 based on a mapping of information found in medical physiology and pathophysiology texts, such as Guyton and Hall (1996), McCance and Huether (1999) and Oh (1997).

Information in the medical texts was placed into each VSM Function within each level of recursion and was described generically in terms of gradients, the processes that dissipate these gradients, and associated anatomical structures. A small sample of the information inventory which was also an outcome of Phase 1 is shown as an insert in Figure 1. The information inventory was derived from coded interview transcript data. There were 57 interview transcripts—27 nurse and 30 doctor transcripts. The speech units from the interview transcripts were coded according to DF and RH coordinates which located the speech unit within the overall RDF matrix.

Once all speech units had been mapped to the RDF, they were edited to remove identifying language and duplication. In this way an aggregated inventory of generic speech units was developed. As well as showing the information resources available, the inventory also provided insights as to the state spaces within which information could move.

Using these resources a skeletal framework that partitioned available design 'real-estate' was developed as shown in the top right-hand corner of Figure 2. The next step in the design process was to design specific elements.

Design elaboration and refinement

Developing specific design elements involved an iterative 'scenario' based design-evaluate protocol (Carroll, 1997). The scenarios used in design were not constructed by the researcher. Instead, 10 complete and de-identified ICU patient data sets were acquired with Ethics Committee approval and in consultation with the Medical Director (Dr. John Reeves) of the Epworth Hospital ICU, Melbourne, Australia. Six data sets were used to develop the paper prototype and four were set aside for design evaluation.

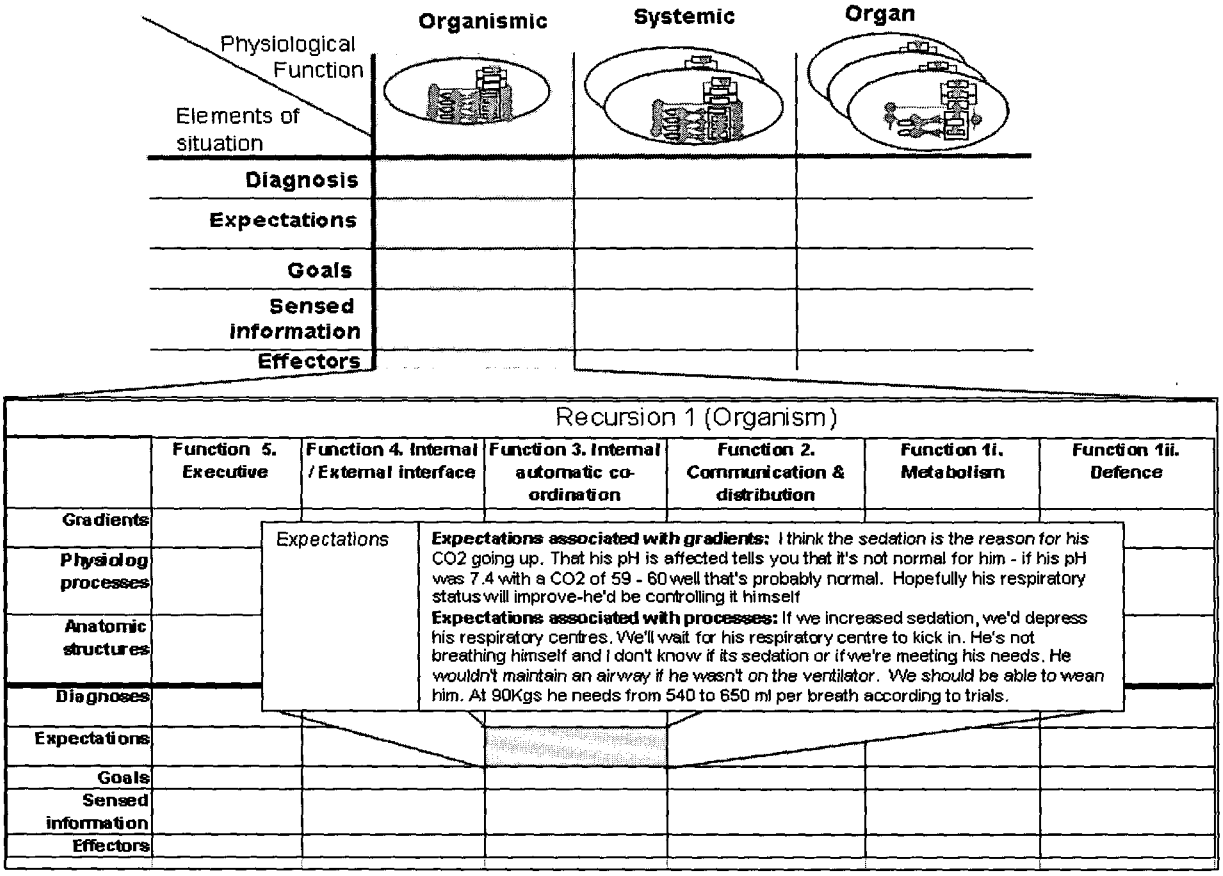

Figure 1. The RDF with a small sample of the information inventory.

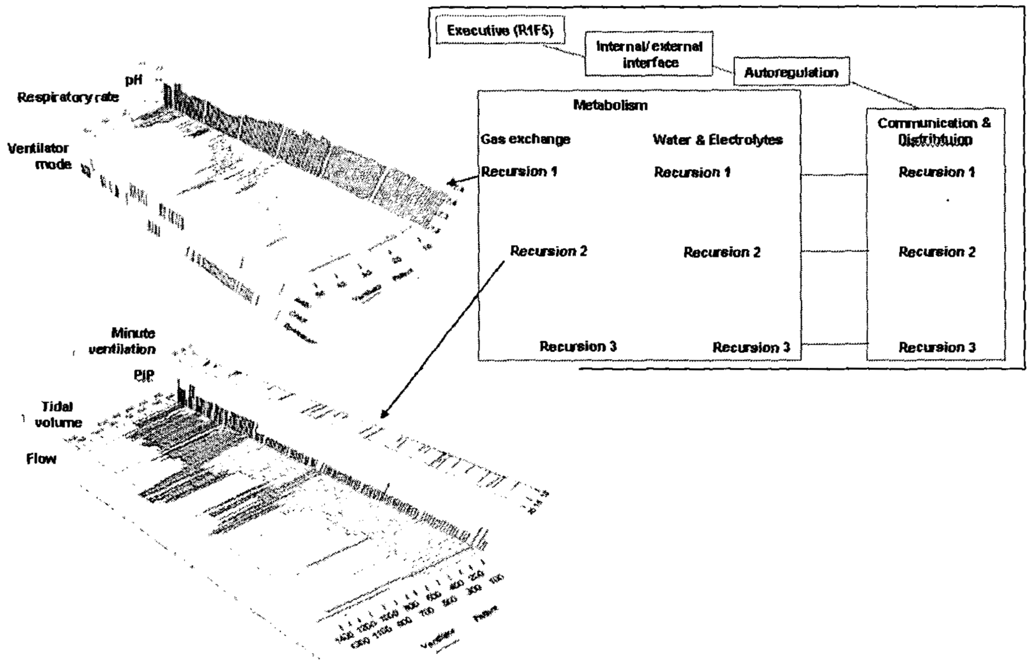

Figure 2. Overall structure and two final design elements.

Areas of lack of 'fit' provided a basis for design refinement and elaboration. This process was iterated across the six data sets.

Design iterations accommodated time and integrated RH based gradient–dissipative process relations with the DF elements of situation. Resolving issues in each of these areas, design converged to a basic element shape that took slightly different forms depending on the type of data being displayed (continuous, discontinuous, categorical, numerical etc).

Some of the more influential design principles included the 'dynamics as figural change' and 'time as perspective' principles from Hansen (1995) plus various quantitative data display principles from Tufte (1983) and Spence (2001).

To illustrate these principles in action, Figure 3 shows data for the VSM Function 'Respiration' at its highest level of recursion. Time is represented from the rear of the figure (past) to the front (present) and is marked by recordings taken within and across 24-hour periods.

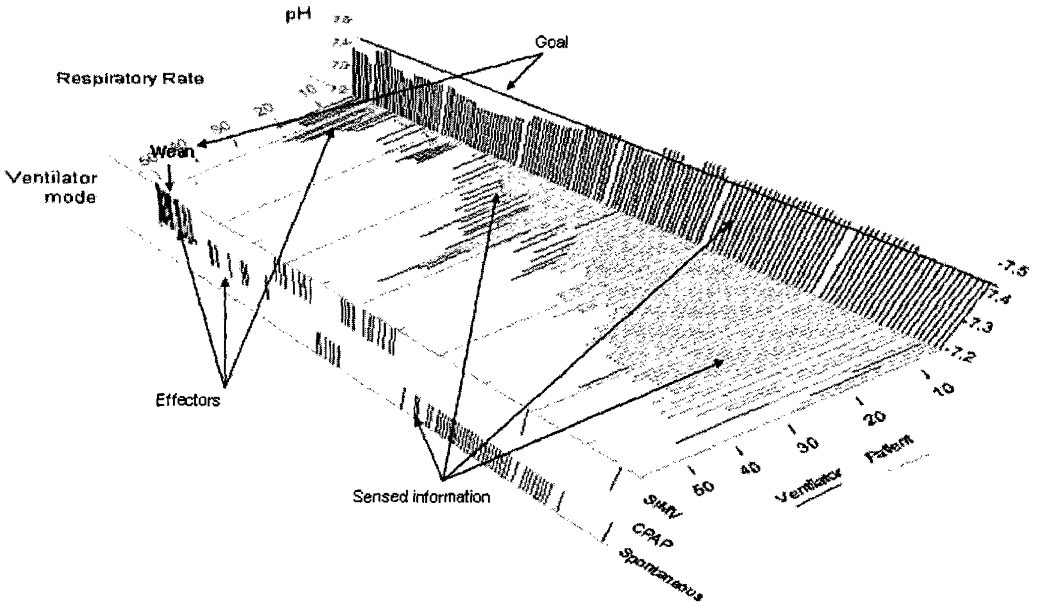

Figure 3. Design element for 'Respiration'.

In Figure 3, pH (the gradient driver of respiration) is positioned at the top. The line running through pH is the medically prescribed goal for pH which in this patient data set did not change. Respiratory rate (beneath pH) is part of the dissipative process that responds to changes in the pH gradient. Thus the gradient–dissipative process relationship between pH and respiratory rate is integrated visually by proximity. In the ICU, respiratory rate can either be a function of the patient's own rate (see light lines) or can be set and externally manipulated via a mechanical ventilator (see dark lines). Thus the relationship between physiological processes and medical actions (the ventilator respiratory rate) is clarified.

This representation conforms to the design goals associated with the representation of physiological functions and in part accommodates design goals associated with 'if...then' reasoning. Due to the limitations of static paper-based representation, time and change relations were not attempted in great detail. This will be the focus for design in an electronic prototype capable of including animation and 3-D representation.

DISCUSSION

This paper presented a process for the design of an information representation aimed at making visible physiologically-related, decision-relevant information that supports black box inferential problem solving. The design process began with an RDF model based on actual information use in the ICU.

The RH from the initial framework was used to structure information within available real-estate. Thus physiological relationships provided the skeletal structural. Design goals defined in phase 1 helped to prioritise the design effort. Thus design focussed on physiologically relevant relationships, the broad representation of time, and the association of some elements of situation with physiological data.

The information inventory that was also an output of Phase 1 was used to group information within discrete but often complex design elements. The design process proceeded until four major physiological functions were represented, some to the third level of recursion within the VSM.

Once completed, the design was evaluated experimentally against a conventional paper-based patient observation chart (Miller & Sanderson, 2003). The experimental tasks were designed to determine whether the new design supported more efficient information processing as would be expected from a design that emphasised information design on the basis of physiological and decision relationships. The results of the evaluation support the view that the design produced by the process reported here supports efficient information processing by senior medical and nursing staff.

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