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Health professional workstations and their integration in a hospital information system: the pragmatic approach MEDIAS

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Abstract

Within the daily workload at a ward there is a considerable amount of information processing. It is the task of a systematic management of hospital information systems to provide health professionals with the right information in the right place at the right time. This paper deals with the consequences for the management of hospital information systems if health professional workstations are introduced as a means for this information logistic and with the experiences gained in the Heidelberg University Hospital. Health professional workstations are formally defined in the context of a three level graph-based model of hospital information systems. It is found that health professional workstations have communication needs not only on the physical level of computer systems in the hospital information system but also on the logical tool level, which is the level of application systems. On this level communication servers or brokers are of considerable importance. In Heidelberg there are about 200 health professional workstations (MEDIAS) in routine use.

Keywords: Communication servers; Communication standards; Hospital information systems; Health professional workstations; Integrated advanced medical information systems (IAMIS)

“The Health Care Professional Workstation (HCPW) provides a portal to the health care system as a whole. Through this portal the health care professional must be able to carry out a wide variety of tasks in an integrated fashion.” [1]

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1. Introduction and problem

1.1. Information processing and communication on a ward and the tools provided by a heterogeneous hospital information system

Within the daily workload on a ward there is a considerable amount of information processing and communication activities. These are, for example, the maintenance of the patients' records, planning and documenting of nursing, clinical documentation, maintenance of registers and subsequently their analysis, requests for drugs and other material, ordering meals and central services, performing order entry, receipt of lab reports, ADT (admission, discharge, transfer), searching for medical knowledge, for example, information about drugs or diseases, work scheduling, creation of statistics, documenting nursing actions and diseases etc. ([2–6]).

Considering this information processing as a part of the respective hospital's information system we have to take into account, that especially heterogeneous hospital information systems tend to be 'self-evolutionary' or even 'chaotic'. There will be, however, severe consequences for hospital information systems if they are not managed systematically. The tools provided by those hospital information systems (taking both its computer supported and its conventional part into account) are too often nearly as numerous as the procedures they are destined to support. Thus the medical staff has to shift for example between the use of a fax for material requests, a phone to asking for lab reports, a computer terminal for ADT actions, a personal computer, which is situated in the doctor's room, for retrieving medical knowledge for a drug or literature database, paper forms for order entry and so on.

Obviously, this shift between media and tools is very time consuming and inclines to demotivate medical staff deeply.

1.2. Tasks within the management of heterogeneous hospital information systems

Within heterogeneous hospital information systems, application systems have to — or at least

should — cooperate closely ([7]) in order to obtain a high degree of interoperability. In addition, there is a strong demand for functional integration and user interface integration (e.g. [8], see also [9,10]). The latter holds true especially for the situation on wards as described above and it is the prerequisite to be able to support patient care and medical research adequately and for keeping information processing in hospitals economic.

Consequently it is the task of a systematic management of hospital information systems, i.e. its systematic design and supervision, to provide health professionals with

- the right information in the right place at the right time;
- information processing tools, which are best suited for obtaining and delivering the information;
- needed tools on as few media as possible;
- access to the tools at, or at least close to, the site, where the information processing that is to be supported has to be carried out;
- access to the tools in a convenient and uniform way.

1.3. Intention of this paper

This paper deals with the consequences for the management of hospital information systems if health professional workstations are introduced in a hospital and with the experiences gained in the Heidelberg University Hospital. We want to answer the following questions in detail:

- (1) How can a health professional workstation and its interface to a hospital information system be defined precisely and what might be the benefit of a formal definition?
- (2) What is the influence on communication in the related hospital information system which is implied by the information needs on the health professional workstation?
- (3) How can convenient and uniform access to the information processing tools be realized at reasonable costs?
- (4) What is the architecture of the health professional workstation MEDIAS at Heidelberg University Hospital?

- (5) What experiences have been gained at Heidelberg University Hospital?
- (6) What are the related approaches to realize health professional workstations in international literature?
- (7) What are the consequences for the management of hospital information systems if health professional workstations are to be introduced.

In Section 2 a model of a health professional workstation is introduced with respect to a three level graph-based model of a hospital information system. Section 3 deals with the health professional workstation MEDIAS in the Heidelberg University Hospital Information System as an application of this model. Section 4 introduces some qualities of health professional workstations. In Section 5 MEDIAS is examined with respect to those qualities. A discussion of related approaches is given in Section 6, and the answers to the questions listed above are given in Section 7.

2. Modelling health professional workstations

2.1. Hospital information systems

Let us denote a hospital information system as the partial system of a hospital, which deals with the complete information processing and information storing of the hospital. That part of a hospital information system, where computers are used as information processing tools, is denoted as the computer-supported part of a hospital information system [11,12].

As pointed out in more detail in [11,12] hospital information systems can be considered as distributed systems consisting of co-operating objects performing information processing. In a three level graph-based model (3LGM) the objects can be classified as information procedures forming a procedure level, as application systems forming a logical tool level and as physical subsystems forming a physical tool level of the hospital information system (Fig. 1).

On the procedure level the functionality of a hospital information system can be described.

Nodes in a procedure level graph are 'information procedures' which have to carry out certain information processing activities. Those procedures can be compared with what is called 'business functions' in [13]. Edges in this graph correspond to an information interchange between the information procedures. Certain symbols called 'procedure access' refer to some information procedures which can be used directly by hospital information system users and thus form the entry-points for users into the hospital information system at procedure level.

So if we denote \underline{P} as a set of information Procedures, \underline{AP} as a set of Procedure Accesses, $\underline{P} \cap \underline{AP} = \emptyset$, $\underline{II} := (\underline{P} \times \underline{P}) \cup (\underline{AP} \times \underline{P}) \cup (\underline{P} \times \underline{AP})$ as a set of Information Interchanges, then the graph $\text{PLG} := (\underline{P} \cup \underline{AP}, \underline{II})$ can be denoted as the Procedure Level Graph.

The first step of describing the tools required by the information procedures is done at the logical tool level of a hospital information system. The corresponding logical tool level graph consists of nodes, which represent 'application systems'. Application systems are for example installations of application software products on computers. Certain symbols called 'functions' serve as entry-points for users which represent functions offered by application systems. Using appropriate mappings information procedures and procedure accesses, respectively, can be formally related to those application systems and functions, respectively, which are used to enable them. On this level, functions are users' entry-points to the hospital information system and thus realise the access to information procedures. The communication of messages between application systems is represented by edges between the corresponding nodes in the logical tool level graph.

Similarly to the above we can obtain a Logical Tool Level Graph $\text{LTLG} := (\underline{A} \cup \underline{FA}, \underline{CI})$ if we let \underline{A} denote a set of Application systems, \underline{FA} a set of Functions of such Application systems and $\underline{CI} := (\underline{A} \times \underline{A}) \cup (\underline{FA} \times \underline{A}) \cup (\underline{A} \times \underline{FA})$ a set of Communication Interfaces. The mapping to relate the procedure level to the logical tool level can formally be described by $\alpha: (\underline{P} \cup \underline{AP}) \rightarrow \wp(\wp(\underline{A} \cup \underline{FA}))$ where $\wp(\underline{X})$ denotes the power set of \underline{X} and $\alpha(x) := \alpha_1(x)$ with $\alpha_1: \underline{P} \rightarrow \wp(\wp(\underline{A}))$ if $x \in \underline{P}$ and

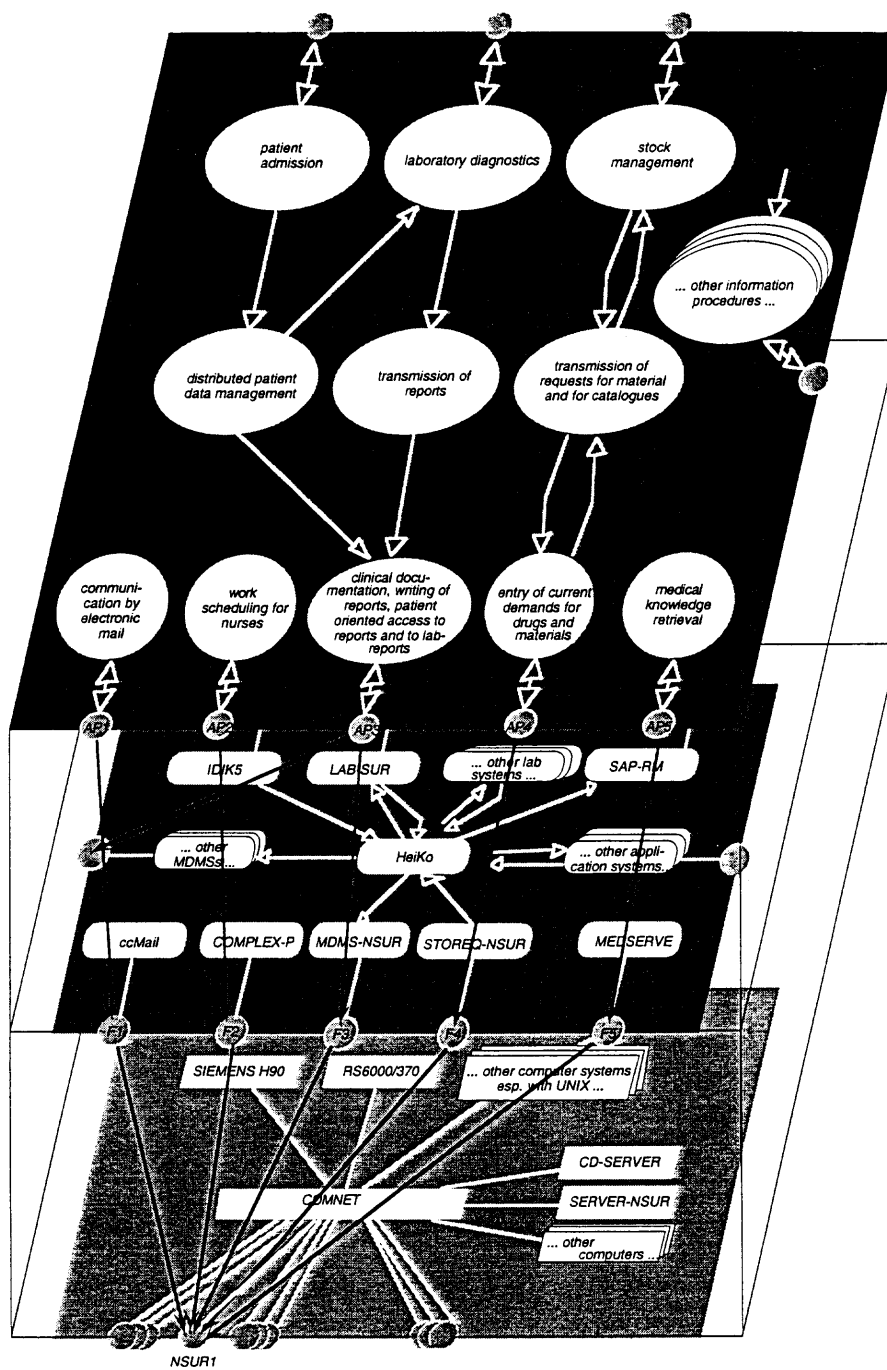


Fig. 1. Example of a three level graph-based model of a hospital information system.

$\alpha(x) := \alpha_2(x)$ with $\alpha_2: \underline{AP} \rightarrow \wp(\wp(\underline{FA}))$ if $x \in \underline{AP}$. This means that procedures are mapped on sets of possible configurations of application systems and procedure accesses are mapped on respective sets of functions.

As a second step, the physical tools of information processing are described at the physical tool

level of a hospital information system. They can be joined appropriately in order to form so-called 'physical subsystems'. The physical subsystems are represented as nodes of a physical tool level graph. In the computer-supported part of a hospital information system physical subsystems are computer systems. Again there are entry-points at

the physical tool level which now are called ‘terminals’; terminals in this sense are not only computer terminals but also personal computers or printers. Application systems and functions, respectively, can now be mapped on-to physical subsystems and/or terminals; each mapping thereby describes which physical subsystems are the physical basis of the respective application systems. Edges in the physical tool level graph represent a data interchange between physical subsystems.

Let \underline{PS} denote a set of Physical Subsystems, \underline{TPS} a set of Terminals of Physical Subsystems and $\underline{DI} := ((\underline{PS} \cup \underline{TPS}) \times (\underline{PS} \cup \underline{TPS}))$ a set of Data transmission Interfaces. So $\text{PTLG} := (\underline{PS} \cup \underline{TPS}, \underline{DI})$ describes the Physical Tool Level Graph. The mapping to relate the logical tool level to the physical tool level can formally be described by $\beta: (\underline{A} \cup \underline{FA}) \rightarrow \wp(\wp(\underline{PS} \cup \underline{TPS}))$ where $\beta(x) := \beta_1(x)$ with $\beta_1: \underline{A} \rightarrow \wp(\wp(\underline{PS} \cup \underline{TPS}))$ if $x \in \underline{A}$ and $\beta(x) := \beta_2(x)$ with $\beta_2: \underline{FA} \rightarrow \wp(\wp(\underline{TPS}))$ if $x \in \underline{FA}$. That means that application systems are mapped on sets of possible configurations of physical subsystems and/or terminals and functions are mapped on corresponding sets of terminals only.

On the basis of the procedure level defined before and the logical and physical tool levels, a definition of a three level graph-based model, or 3LGM, can now be given for hospital information systems: the quintuple $(\text{PLG}, \text{LTLG}, \text{PTLG}, \alpha, \beta)$ is a three level graph-based model, or briefly 3LGM, of a hospital information system.

By this definition we also have a means for describing the term ‘heterogeneity’. So we can say that a hospital information system is heterogeneous if the cardinality of \underline{A} is greater than 1. Even if there are lots of computer systems in a hospital we can actually talk of a homogeneous information systems if there is only one application system installed on them (in a distributed manner).

2.2. Health professional workstations

Within the 3LGM it is now possible to define precisely, what we usually call a health professional workstation. Reflecting 3LGM a health professional workstation is characterized by, for

example, a personal computer, i.e. a terminal as defined before, a set of functions offered to users on that terminal and a set of accesses to procedures, which are thereby realized on the terminal or personal computer for example. Thus a health professional workstation is nothing but a information sub-system of the corresponding hospital information system in the sense of [11].

Let us denote, as defined above, $(\text{PLG}, \text{LTLG}, \text{PTLG}, \alpha, \beta)$ a 3LGM of a certain hospital information system and let $T, T \in \underline{TPS}$, be a terminal as for example a personal computer. Furthermore let

- $\text{PTLG}_T := (\{T\}, \emptyset)$,
- $\text{LTLG}_T := (\underline{A}_T \cup \underline{FA}_T, \underline{CI}_T)$ with $\underline{A}_T := \{A \in \underline{A} \mid \{T\} \in \beta(A)\}$, $\underline{FA}_T := \{F \in \underline{FA} \mid \{T\} \in \beta(F)\}$, $\underline{CI}_T := \{(x, y) \in \underline{CI} \mid x \in (\underline{A}_T \cup \underline{FA}_T) \wedge y \in (\underline{A}_T \cup \underline{FA}_T)\}$,
- $\text{PLG}_T := (\underline{P}_T \cup \underline{AP}_T, \underline{II}_T)$ with $\underline{P}_T := \{P \in \underline{P} \mid \exists x \subseteq \underline{A}_T: x \in \alpha(P)\}$, $\underline{AP}_T := \{AP \in \underline{AP} \mid \exists y \subseteq \underline{FA}_T: y \in \alpha(AP)\}$, $\underline{II}_T := \{(x, y) \in \underline{II} \mid x \in (\underline{P}_T \cup \underline{AP}_T) \wedge y \in (\underline{P}_T \cup \underline{AP}_T)\}$.

Definition of health professional workstation

The triple $\text{HPW}_T := (\text{PLG}_T, \text{LTLG}_T, \text{PTLG}_T)$ is the health professional workstation on the terminal T in the hospital information system modelled by the 3LGM $(\text{PLG}, \text{LTLG}, \text{PTLG}, \alpha, \beta)$.

So on the one hand it can be shown that a health professional workstation at a certain terminal offers the functionality modelled by \underline{FA}_T , which means that the procedure accesses in \underline{AP}_T can actually be used there. On the other hand the set \underline{A}_T shows, to what extent the workstation also serves as a computing facility, i.e. a physical subsystem, in order to realize application systems and in the end realize entire procedures, as modelled in \underline{P}_T . For a deeper understanding please refer to Section 3 which also serves as an example of the definition above.

On this basis, the interface of a health professional workstation to the remainder of the hospital information system can be defined as well. Let be $T, T \in \underline{TPS}$, as above, a terminal, for example a personal computer, and HPW_T a health professional workstation in the hospital information

system modelled by the 3LGM (PLG, LTLG, PTLG, α , β).

Definition interface of a health professional workstation

The triple $HPW_{T^*} := (\underline{II}_{T^*}, \underline{CI}_{T^*}, \underline{DI}_{T^*})$ is the interface of the health professional workstation HPW_T to the hospital information system modelled by the 3LGM (PLG, LTLG, PTLG, α , β) iff

- $\underline{DI}_{T^*} = \{(x, y) \in \underline{DI} \mid (x = T \wedge y \neq T) \vee (y = T \wedge x \neq T)\}$,
- $\underline{CI}_{T^*} = \{(x, y) \in \underline{CI} \mid (x \in (\underline{A}_T \cup \underline{FA}_T) \wedge y \in ((\underline{A} - \underline{A}_T) \cup (\underline{FA} - \underline{FA}_T)) \vee (y \in (\underline{A}_T \cup \underline{FA}_T) \wedge x \in ((\underline{A} - \underline{A}_T) \cup (\underline{FA} - \underline{FA}_T)))\}$,
- $\underline{II}_{T^*} := \{(x, y) \in \underline{II} \mid (x \in (\underline{P}_T \cup \underline{AP}_T) \wedge y \in ((\underline{P} - \underline{P}_T) \cup (\underline{AP} - \underline{AP}_T)) \vee (y \in (\underline{P}_T \cup \underline{AP}_T) \wedge x \in ((\underline{P} - \underline{P}_T) \cup (\underline{AP} - \underline{AP}_T)))\}$.

This definition of an interface between a health professional workstation and its surrounding hospital information system clearly shows that those interfaces must be realized not only between computer systems. Problems related to interfaces are rather to be solved at all three levels of the hospital information system concerned.

3. The health professional workstation MEDIAS in the Heidelberg University Hospital information system

3.1. The Heidelberg University Hospital information system

The Heidelberg University Hospital comprises 62 medical departments with 117 wards, 70 outpatient units, 31 operating theatres for inpatients and additional ones for outpatients. About 6000 persons are employed in the fields of research, education and patient care (1994). The number of inpatient stays reaches about 50 000 per year, the number of outpatients is about 200 000. The Heidelberg University Hospital information system is highly heterogeneous on its logical as well as on its physical tool level ([14]).

Fig. 1 gives an insight into a part of the information system by the graphical representation of its 3LGM. Besides the information procedures there are procedure accesses AP1, AP2, AP3, AP4, and AP5 and others. At the logical tool level the application system IDIK5 is the patient management system, LAB-CHIR, a lab software installation in the surgical clinic, SAP-RM, the stock management system, MDMS, an application software for medical document management and MDMS-NSUR, one of MDMS's installations in the neurosurgical clinic, HeiKo, the Heidelberg communication system [15], STOREQ-NSUR, an application system for material requests in the neurosurgical clinic, COMPLEX-P, a work scheduler and ccMail, the e-mail system used in Heidelberg University Hospital. MEDSERVE is a medical knowledge server [16]. The application systems' functions referred subsequently are called F1, F2, F3, F4, F5. At the physical tool level the SIEMENS computer is the central mainframe, PRIME and UNIX computers are mainly used in the laboratories, SERVER-NSUR is for the MDMS-NSUR application system, CD-SERVER is the file server for MEDSERVE and COMNET is the communication network with all its active and passive components. The personal computer NSUR1, which is a terminal on a ward of the neurosurgical clinic, is extracted among the other terminals.

Let $(PLG_{HD}, LTLG_{HD}, PTLG_{HD}, \alpha_{HD}, \beta_{HD})$ be formally the 3LGM of the Heidelberg University Hospital information system. Whereas the PLG_{HD} , $LTLG_{HD}$ and $PTLG_{HD}$ can be derived (at least in part) from Fig. 1, α_{HD} and β_{HD} shall be outlined in Tables 1 and 2 as far as the next section about MEDIAS is concerned.

3.2. The health professional workstation MEDIAS

3.2.1. Overview

Health professional workstations in the Heidelberg University Hospital Information System are called MEDIAS (MEDizinisches Arbeitsplatz System).

MEDIAS workstations are based on personal computers and installations are mainly located on

Table 1
Mapping α

| Procedure P or procedure accesses AP | Realising application systems or functions: $\alpha_1(P), \alpha_2(AP)$ |
|---|--|
| Communication by electronic mail | {{ccMail}} |
| AP1 | {{F1}} |
| Work scheduling for nurses (in test phase), working hours recording, and statistical analysis | {{COMPLEX-P}} |
| AP2 | {{F2}} |
| Clinical documentation, especially writing of medical and operation reports, providing patient-oriented access to these reports and to those of laboratory, radiology, and other functional units | {{MDMS-NSUR}, {MDMS-...},...} |
| AP3 | {{F3},...} |
| entry of current demands for drugs and materials | {{STOREQ-NSUR}, {STOREQ-...},...} |
| AP4 | {{F4},...} |
| medical knowledge retrieval | {{MEDSERVE}} |
| AP5 | {{F5}} |
| ... | ... |

Table 2
Mapping β

| Application system A or function F | Realising physical subsystems or terminals: $\beta_1(A), \beta_2(F)$ |
|------------------------------------|--|
| ccMail | {{some other server, COMNET, NSUR1},...} |
| F1 | {{NSUR1},...} |
| COMPLEX-P | {{some other server, COMNET, NSUR1},...} |
| F2 | {{NSUR1},...} |
| MDMS-NSUR | {{SERVER-NSUR, COMNET, NSUR1},...} |
| F3 | {{NSUR1},...} |
| STOREQ-NSUR | {{NSUR1}} |
| F4 | {{NSUR1}} |
| MEDSERVE | {{CD-SERVER, COMNET, NSUR1},...} |
| F5 | {{NSUR1},...} |
| ... | ... |

wards, in offices (for medical report writing) and in operating theatres (for operation documentation) but also for example in physicians' rooms, offices of the head nurses and in libraries.

Taking the personal computer NSUR1 on ward 2 of the neurosurgical clinic (Fig. 1) as an example for a MEDIAS computer (i.e. a computer which 'bears' the workstation MEDIAS), we have a MEDIAS installation which provides access to all currently accessible information procedures.

According to the definitions above the formal description of the MEDIAS installation for example on the NSUR1-computer is:

$MEDIAS_{NSUR1} := (PLG_{NSUR1}, LTLG_{NSUR1}, PTLG_{NSUR1})$ and so the interface to the surrounding hospital information system is then described by $MEDIAS_{NSUR1}^* := (\underline{II}_{NSUR1}^*, \underline{CI}_{NSUR1}^*, \underline{DI}_{NSUR1}^*)$.

The details are discussed in the following subsections.

3.2.2. Architecture and interface at procedure level

At the beginning of 1995 $MEDIAS_{NSUR1}$ could be described at the procedure level by

$$PLG_{NSUR1} := (\underline{P}_{NSUR1} \cup \underline{AP}_{NSUR1}, \underline{II}_{NSUR1})$$

with $\underline{P}_{NSUR1} := \{\text{entry of current requests for drugs and materials}\}$, $\underline{AP}_{NSUR1} := \{AP1, AP2, AP3, AP4, AP5\}$, and $\underline{II}_{NSUR1} := \{\text{entry of current requests for drugs and materials, AP4}\}$.

That means that MEDIAS provided access to the information procedures

- clinical documentation, especially writing of medical and operation reports, providing patient-oriented access to these reports and to those of laboratory, radiology and other functional units (AP3),

- entry of current requests for drugs and materials (AP4) and
- medical knowledge retrieval (AP5).
- work scheduling for nurses (in test phase), working hours recording, and statistical analysis (AP2),
- communication by electronic mail (access AP1),

Only the procedure 'entry of current requests for drugs and materials' is entirely realized at the corresponding personal computer. In addition, general text processing and computing facilities are offered.

The interface of MEDIAS to the information procedures in the remainder of the hospital can be described by

\underline{II}_{NSUR1}^* :

=
 {(entry of current requests for drugs and materials,
 transmission of requests for material...),
 (AP1, communication...),
 (AP2, work scheduling...),
 (AP3, clinical documentation...),
 (AP5, medical knowledge...),...
 < and vice versa > ...}.

A brief analysis of the procedure level graph of the Heidelberg University Hospital Information System in Fig. 1 shows clearly, that even at this level there is a strong demand for an intensive information interchange between the information procedures. If the underlying logical and physical tool levels would not realize this interchange, MEDIAS could not provide information like the result of a lab examination at the access point AP3 and, for example, a demand for materials could actually not be delivered to the stock management. That means that a systematic management of the corresponding hospital information system has not only to realize the accesses to procedures and the interface \underline{II}_{NSUR1}^* but also all the other information procedures and information interchanges; otherwise health professional workstations do not make sense.

3.2.3. Architecture and interfaces at logical tool level

At the logical tool level MEDIAS is currently characterized by

$LTLG_{NSUR1} := (\underline{A}_{NSUR1} \cup \underline{FA}_{NSUR1}, \underline{CI}_{NSUR1})$

with $\underline{A}_{NSUR1} := \{\text{STOREQ-NSUR}\}$, $\underline{FA}_{NSUR1} := \{F1, F2, F3, F4, F5\}$, and $\underline{CI}_{NSUR1} := \{(\text{STOREQ-NSUR}, F4)\}$.

It follows that in analogy to the procedure level there is only one application system—the STOREQ-NSUR application for the entry of current requests for drugs and materials—entirely realized on the NSUR1 computer. Additionally there are the functions F1, F2, F3, F4, F5 to get use of the related application systems. Having no other application system entirely realized on NSUR1 there must be other computers, i.e. servers to realize them. The description of the interface to the remainder of the hospital information system shows the application systems concerned:

$\underline{CI}_{NSUR1}^* := \{(\text{STOREQ} - \text{NSUR}, \text{HeiKo}),$
 $(F1, \text{ccMail}), (F2, \text{COMPLEX} - P),$
 $(F3, \text{MDMS} - \text{NSUR}), (F5, \text{MEDSERV}), \dots$
 $\langle \text{and vice versa} \rangle \dots\}$.

Indeed the application systems ccMail, COMPLEX-P, MDMS-NSUR, and MEDSERV (for the relation between information procedures and this application systems please refer to Table 1) use servers running NOVELL NETWARE for their databases. The corresponding communication interfaces therefore realize database accesses. As STOREQ-NSUR is entirely realized on NSUR1 its communication interface to the Heidelberg communication system HeiKo must also be realized (in part) on NSUR1. HeiKo provides communication services to application systems by means of standardized 3rd generation programming language interfaces for sending and receiving messages. The messages are formatted according to an HL7-like in-house standard and thus enables the understanding of incoming or outgoing patient data and reports for example. The interfaces for sending and receiving are available for all operating systems

(BS2000, PRIMOS, DOS, UNIX,...) used in the Heidelberg University Hospital. As MDMS-NSUR needs a message interchange as well it also has such a communication interface to HeiKo. This is the prerequisite for the information interchange at the procedure level called for in the previous subsection.

The application systems ccMail and COMPLEX-P are based on commercially procured application software products. STOREQ-NSUR, MDMS-NSUR, and MEDSERV are self developed.

After switching on a MEDIAS computer a simple menu is presented to the user. Only privileged users are able to use the operation system level (i.e. MS-DOS). The menu is to map the user's desired information procedure to the application system realising it. So if a user, for example, selects 'clinical documentation' an underlying shell will start running the application system to support clinical documentation, writing of medical and operation reports, providing patient-oriented access to these reports and to those of the laboratory, radiology and other functional units. Therefore at the NSUR1 MEDIAS computer it is MDMS-NSUR that is started from the SERVER-NSUR. After having automatically started the application system needed, the particular user interface of that application system is offered to the user. If 'quit' is entered the application system control is returned to the shell and thus the menu will be presented again. The menu is site dependent and can be customized by a mere table.

3.2.4. Architecture and interface at physical tool level

MEDIAS at the physical tool level is quite simple and is characterized by

$$PTLG_{NSUR1} := (\{NSUR1\}, \emptyset),$$

$$DI_{NSUR1}^*$$

$$:= \{(NSUR1, COMNET), (COMNET, NSUR1)\}.$$

Being based on the use of personal computers under MS-DOS and MS-WINDOWS (with a 386 processor or higher) computers like NSUR1 need to be connected to the computer network of the Heidelberg University Hospital. The communica-

tion network provides 10baseT cables to connect the workplaces' sockets with its active components. In this area the ETHERNET protocol is used. For connecting the in-house nets a backbone based on optical fibres and running a FDDI protocol is used. Besides TCP/IP services the NOVELL protocol is used to access corresponding servers at the physical tool level. While TCP/IP is mainly used by the communication interfaces provided by HeiKo, the NOVELL protocol serves to connect the functions to their related application systems.

So all MEDIAS computers like NSUR1 have an ETHERNET board and appropriate TCP/IP and NOVELL software installed and there are no extraordinary requirements on MEDIAS computers.

Every MEDIAS computer is connected to a printer at a reasonable distance via the communication network. If appropriate there is a bar-code scanner available as a mobile data entry device. The bar-code scanners are especially employed for entering the demand for drugs and other materials on the ward. The keyboards are usually equipped with a reader for magnetic tape cards; this is to input patient identification data from the patient card, which is issued by the hospital at admission time.

4. Qualities of health professional workstations

4.1. Qualities at procedure level

As called for in the introduction, health professional workstations shall serve health professionals in getting the right information in the right place at the right time. This service has to be provided for both the areas of education and research and of patient care [17,18]. As stated, for example, in [2,3,6,19–22] especially 'point of care systems' [2] on wards and ambulatory care units should therefore among others provide access to the following information procedures:

- fundamental documentation and hospital-based diagnosis statistics,
- nursing documentation, patient records,

- clinical documentation including writing of medical and operation reports, providing patient-oriented access to these reports and to those of laboratory, radiology, and other functional units,
- requests for dates in functional units,
- entry of current requests for drugs and materials,
- order entry and results report,
- resource management,
- management of human resources including work scheduling, recording of working hours, and statistical analysis,
- work flow management in ambulatory care,
- calendar management,
- medical knowledge retrieval,
- knowledge based support for diagnosis and therapy,
- admission, discharge, and transfer of patients [23].

There are needs for other information procedures in other sites and areas of hospitals, but within the context of this article we will focus on what is happening in patient care units.

4.2. Qualities at logical tool level

According to our introductory remarks on the appropriate support of health professionals in the field of information processing there are two requirements for health professional workstations that seem to be in conflict with each other. One is the demand for 'information processing tools, which are best suited for obtaining and delivering the information' and the other is to provide 'access to the tools in a convenient and uniform way'. There is conflict because especially in big hospitals, for example the Heidelberg University Hospital, the choice of the best suited tools will often result in the acquisition of heterogeneous application software products and thus produce a landscape of heterogeneous application systems. But even if there may be no problem in acquiring software products with convenient user interfaces here may actually be a problem in providing uniform access to the heterogeneous tools.

The solution of this problem is often called 'functional integration' ([8]). Quite far from that

we want to deal here with the question of how a uniform use of different functions of different and heterogeneous application systems can be achieved. In our opinion one can distinguish between three levels of uniformity at a health professional workstation:

- level 0: no uniformity,
- level 1: uniform access to application systems,
- level 2: uniform functions.

Let a personal computer be attached to the hospital wide communication network and having installations of NETWARE and TCP/IP on it. This computer is thus providing the possibility of getting access to whatever application system of the hospital information system the user wants to use. Access is realized by explicitly choosing the appropriate servers and executing the appropriate operation system's commands. Let us consider such a health professional workstation as having 'no uniformity'.

A 'uniform access to application systems' can be achieved by providing a menu which enables the user to simply select a procedure giving access to a certain information procedure. The underlying software should then automatically find the application system with the required functions and then attach the respective server, find the application system there and start it. Thus the mapping α between procedures and application systems and the mapping β between application systems and computers together with a mere routing is provided.

The highest level of uniformity achievable in this context is to provide 'uniform functions'. That means to provide the same interface with all functions available at the health professional workstation. Thus, there is a uniform layout and a uniform way of using menus, buttons, function keys etc. and a uniform philosophy or 'look and feel' in using the functions even if they are offered by different application systems. The more heterogeneous a hospital information system is at the logical tool level the more difficult it is to achieve this level of uniformity. Obviously, there should be only a few problems if all application systems concerned are based on the same application software product or even based on application software of the same vendor. But having application

systems based on multi vendor software will cause considerable problems. As presented in [24] an approach for solving this problem is to establish specialized application systems for generating and presenting the needed functions at the workstation. Serving as a shell, such an application system communicates in a synchronous program to program manner with those application systems providing the generic functions and thus doing the job. Difficulties arise if these remote application systems don't provide appropriate interfaces for that kind of communication, but there are pragmatic solutions based for example on 'plugs' [25] or 'wrappers' [26].

4.3. Qualities at physical tool level

Three of the demands made for appropriate support of health professionals in information processing concern the qualities of a health professional workstation at its physical tool level, i.e. to assist health professionals by

- needed tools on as few media as possible;
- access to the tools at, or at least close to, the site, where the information processing to be supported has to be carried out;
- access to the tools in a convenient and uniform way.

The first charge is always fulfilled by a health professional workstation by definition. This is because there should be only one media, i.e. a personal computer or another terminal, which provides all needed functions.

As a consequence of the second demand health professional workstations have to be designed so that they are capable of being employed in all areas of a hospital. Due to the usually restricted size of rooms for nurses and physicians on wards and ambulatory care units and due to the fact that almost always lots of people, including patients, share the rooms the following requirements arise:

- space-saving equipment, i.e. compact computers, flat screens;
- ergonomic equipment, i.e. low radiation colour screen, at least a 15 in. screen, silent printers etc.;

- if mobile data recording is necessary: handy recording devices (e.g. bar-code scanner).

Additionally, a data transmission interface for connecting the workstation to the in-house communication network is necessary.

While convenient access at the physical tool level to the tools is still addressed by the requirements pointed out before, the uniformity of access can be supported at the physical tool level by an in-house standardisation of types of workstation computers and their operating systems. While choosing such a standard one should consider the economical aspects and the requirement for the workstations to run as clients in client-server architectures. Thus, a choice of MS-DOS could be a 'sound general solution' ([27], p. 175) but this holds also for MS-WINDOWS.

4.4. Qualities of the corresponding hospital information system

The demand for providing

- the right information in the right place at the right time
- access to the tools at, or at least close to, the site where the information processing to be supported has to be carried out

is actually the essence of the demands to be fulfilled by the management of a hospital information system if health professional workstations are to be introduced. These demands cannot be achieved only by good design of the health professional workstations but also require an appropriate architecture for the hospital information system as a whole.

Considering how information can be exchanged between a health professional workstation and the rest of the corresponding hospital information system one should analyse the definition of an interface of a health professional workstation introduced before. According to this definition not only interfaces at the physical tool level but also at the logical tool level have to be taken into account.

On the health professional workstation let there be, for example, access to the procedure 'clinical documentation, ...providing patient-oriented access to...reports...'. This procedure needs infor-

mation, i.e. the lab reports, from a procedure 'laboratory diagnostics'.

Thus, if there is not only one application system realising both procedures, there must be a communication interface at the logical tool level so that the corresponding lab application system can send messages which could be interpreted as lab reports. Thus, the management of the hospital information system has to provide a means for communication at the logical tool level. According to our experiences a communication server on the logical tool level [15,28] and the use of standardized protocols like HL7 [29] will essentially support this task. A communication server may be realized on a single computer but can also be distributed over a set of computer systems as described, for example, in [30].

Last but not least data transmission has to be performed on the physical tool level, if the two application systems are installed on different computer systems. Thus, the hospital information system needs an adequate communication network [31].

As a conclusion one can see, that if a lab system has for example an ETHERNET-interface to the communication network but no means for sending reports appropriately and in a standardized manner on the logical tool level the best health professional workstation would be useless.

5. Qualities of MEDIAS

5.1. Qualities at procedure level

Comparing the description of MEDIAS in Section 3.2.2 and the qualities demanded for a medical health professional workstation in Section 4.1 one may be astonished at MEDIAS' poor compliance with the demands. But our experiences have shown the considerable value of the procedure accesses for the users:

- *Clinical documentation, especially writing of medical and operation reports, providing patient-oriented access, for example, to lab reports*

Access to this procedure is provided on 110¹ MEDIAS computers. All operation reports in our hospital are written by using this procedure and thus can use all information of the operation documentation. About 36 000 lab and other reports per month are presented by this procedure. This means that about 35% of all our lab reports are now transported via computer support. An evaluation study showed that by the introduction of this procedure we could increase the rate of reports being on the ward in time from approximately 35 to 75% [32]. Because this helps essentially to reduce patients' length of stay the procedure not only supports health professionals in their tasks of patient care, but also reduces hospital operating costs (e.g. [33,34]).

- *Entry of current requests for drugs and materials*
23¹ MEDIAS computers provide access to this procedure. The need for computer support for this procedure was also derived in [14]. Still in the stage of introduction are MEDIAS computers on two wards providing access to a procedure for ordering meals.
- *Medical knowledge retrieval*
Access to medical knowledge is provided on 132¹ MEDIAS computers. As reported in [16] this procedure is not only used in research but also in patient care approximately 45% of 1887 observed sessions were concerned.
- *Work scheduling for nurses*
The demand for introducing computer supported access to this procedure on MEDIAS was a result of an internal problem and system analysis concerning information and communication needs of nurses [14]. As it is still in a test phase the benefits have not been evaluated up to now.
- *Communication by electronic mail*
This procedure is not so important for use in areas of clinical care, because there are procedures like 'patient-oriented access, for example, to lab reports', which are more appropriate for routine use on wards and outpatient units.

¹ As of July 1995.

5.2. Qualities at logical tool level

According to Sections 3.2.3 and 4 MEDIAS provides level 1 of uniformity at a health professional workstation, i.e. uniform access to application systems. Although this is far from what is usually demanded in literature (e.g. [8,21]) our experiences are satisfactory. As the procedure 'medical knowledge retrieval' itself uses several application software products with heterogeneous and sometimes awkward user interfaces but in our experience only in 1% of the 1887 observed sessions were the user interfaces criticized [16]. Thus our conclusion is that the benefit of components of health professional workstations is much more important than the user interface.

5.3. Qualities at physical tool level

In July 1995 there were about 200 personal computers running as MEDIAS computers in the Heidelberg University Hospital. Up to March the computers were run on MS-DOS but now we are changing stepwise to MS-Windows.

5.4. Qualities of the Heidelberg University Hospital information system

Integration of MEDIAS in the Heidelberg University Hospital Information System is possible because there are appropriate means for communication both at logical and physical tool levels as mentioned before [28].

On the logical tool level there are about 40 autonomous application systems having communication interfaces with the communication system HeiKo (Section 3.2.3). All those application systems use an in-house communication standard, which is an HL7-like communication protocol. Thus, for example four lab systems receive patient data including identification numbers from the ADT system and send lab reports to the MDMS application systems. The patients' identification numbers ensure proper matching of the reports to patients in MDMS. No new application system with a potential of sending or receiving relevant data will be introduced without having a communication interface to HeiKo.

In the beginning of 1995 the communication network on the physical tool level connected the computers of all application systems mentioned before and provided 2845 sockets for workstations all over the hospital. By the end of 1995 all wards shall be equipped with such sockets. Therefore, all MEDIAS computers can now be situated on these sites, where they are needed.

6. Some related approaches to health professional workstations

A lot of papers dealing with health professional workstations are now available in the international literature and a good overview of the current state of the art can be found in the proceedings of a relevant IMIA conference held in 1993 in Washington, DC [21].

The most exciting concepts, which aim to achieve not only level 2 of uniformity but real functional integration of heterogeneous application systems on the logical tool level seem to be HERMES [15,22,35] and HELIOS [35].

As the HERMES project focuses on communication between heterogeneous application systems, an architecture for a hospital information system has been developed rather than a mere concept for health professional workstations. As reported in [25] the use of request brokers [36] is effective for supporting communication on the logical tool level.

The HELIOS concept also refers to request brokers for communication but is rather characterized by high demands on the functionality of health professional workstations and claims that they are 'able to capture, process and display real time sound and video to provide easy access and management of multimedia patient medical records and possibly benefit from vocal or tactile command extensions...' ([35], p. 251). Actual realisation might be hindered by the costs for such workstations and the problem of getting respective data.

Besides these concepts two pragmatic solutions shall be mentioned here.

Scherrer et al. [27] reports on the UNIDOC workstation which is integrated with the DIO-

GENE-2 application system of the Geneva University Hospital information system. While focusing on support for writing of medical reports it also provides access to medical knowledge retrieval by MEDLINE and to administrative and medical procedures by DIOGENE-2. As far as [27] reports, UNIDOC provides level 1 of uniformity. On the physical tool level UNIDOC is based on a client server concept, where MS-DOS clients are connected to UNIX servers.

The Integrated Academic Information Management Systems IAIMS is presented in [18]. As with HERMES, IAIMS is a concept for the hospital information system as a whole rather than a workstation concept and thus shows, that health professional workstations must always be seen as constituent parts of its related hospital information system. IAIMS is reported to have been successfully introduced at the Columbia-Presbyterian Medical Center to support both the areas of education and patient information. About 1000 workstations provide access to the procedures on the procedure level supported by the clinical, scholarly, administrative, and basic research information services. And as UNIDOC IAIMS has level 1 of uniformity.

7. Discussion

Let us now summarize the results by discussing the questions of Section 1.3:

(1) *How can a health professional workstation and its interface to a hospital information system be defined precisely and what might be the benefit of a formal definition?*

Health professional workstations and their interfaces to their related hospital information system are formally defined in Section 2.2. The definitions clarify that in heterogeneous hospital information systems a health professional workstation is not only a part of one of the application systems installed, as for example the patient management or ADT system, but it is an information sub-system of the hospital information system with interfaces on all three of the levels of the remainder of the hospital information system. Correspondingly, a health professional worksta-

tion can be defined formally within a formal model of hospital information systems. Thus it can be shown clearly and in a structured way that such a workstation has an interface to the communication network and to all relevant application systems. It is therefore able to interchange information with information processing procedures which are to provide the information needed by health professionals.

(2) *What is the influence on communication in the related hospital information system which is implied by information needs on a health professional workstation?*

There are communication needs both on the physical tool level and the logical tool level of the hospital information system. While communication networks are needed on the physical tool level there is a need for specialized application systems which offer communication services on the logical tool level as well. In Heidelberg this application system is called HeKo; brokers as described by CORBA [36] seem to be the solution to come. As argued in [37] a 'full level of standards from the physical level through and beyond the applications level' is crucial for being able to 'achieve the necessary seamless interoperability required by workstations for ubiquitous intelligent communications between the workstations and the sources of data' ([37], p. 29). The definition of health professional workstation's interfaces shows especially on the logical tool level that these standards have to encompass the communication between application systems as well as between functions and the remainder of its related application systems. For the communication between application systems on the logical tool level the use of standardized communication protocols like HL7 [29] is appropriate.

(3) *How can a convenient and uniform access to the information processing tools be realized at reasonable costs?*

A pragmatic solution for a convenient and uniform access to the information processing tools can be realized by a uniform access to (heterogeneous) application systems (uniformity of level 1). This can be realized by a simple software shell on the workstation. This shell has to make the access to application systems situated somewhere on a

server in the communication network transparent to the user. Commonly used PCs with an ETHERNET board are sufficient.

(4) *What is the architecture of the health professional workstation MEDIAS at Heidelberg University Hospital?*

The MEDIAS architecture is described in detail in Section 3.2. MEDIAS is based on a PC on the physical tool level. On the logical tool level a shell provides a menu for transparent access to heterogeneous application systems in the Heidelberg University Hospital Information System. Thus, there is access to information procedures like e-mail, work scheduling, documentation, writing and presenting of reports, entry of requests for drugs and materials, and medical knowledge retrieval.

(5) *What experiences have been made at Heidelberg University Hospital?*

There are 185 MEDIAS computers in routine use. It was quite surprising—even for us—to see that the loss of real functional integration and even the awkward user interfaces of some application systems could not impede considerable users' acceptance.

(6) *What are related approaches to realize health professional workstations in international literature?*

A discussion of related approaches can be found in Section 6.

(7) *What are the consequences for the management of hospital information systems if health professional workstations are to be introduced?*

Those responsible for the management of the hospital information system have to provide on the physical tool level:

- an appropriate communication network (a modern optical fibre backbone will be helpful but is no 'conditio sine qua non'),
- commonly used personal computers with connection to the communication network,
- connections to the communication network of all computers being the basis of application systems, which have to deliver messages to the workstation (e.g. a lab system computer).

On the logical tool level:

- an application system which runs as a communication server,

- application systems which provide the functions for presenting the needed information to users and can be accessed as easily as possible from the personal computers mentioned above,
- communication interfaces between the communication server and the application systems for presenting the information,
- communication interfaces between the communication server and the application systems for delivering the information (e.g. a lab system).

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