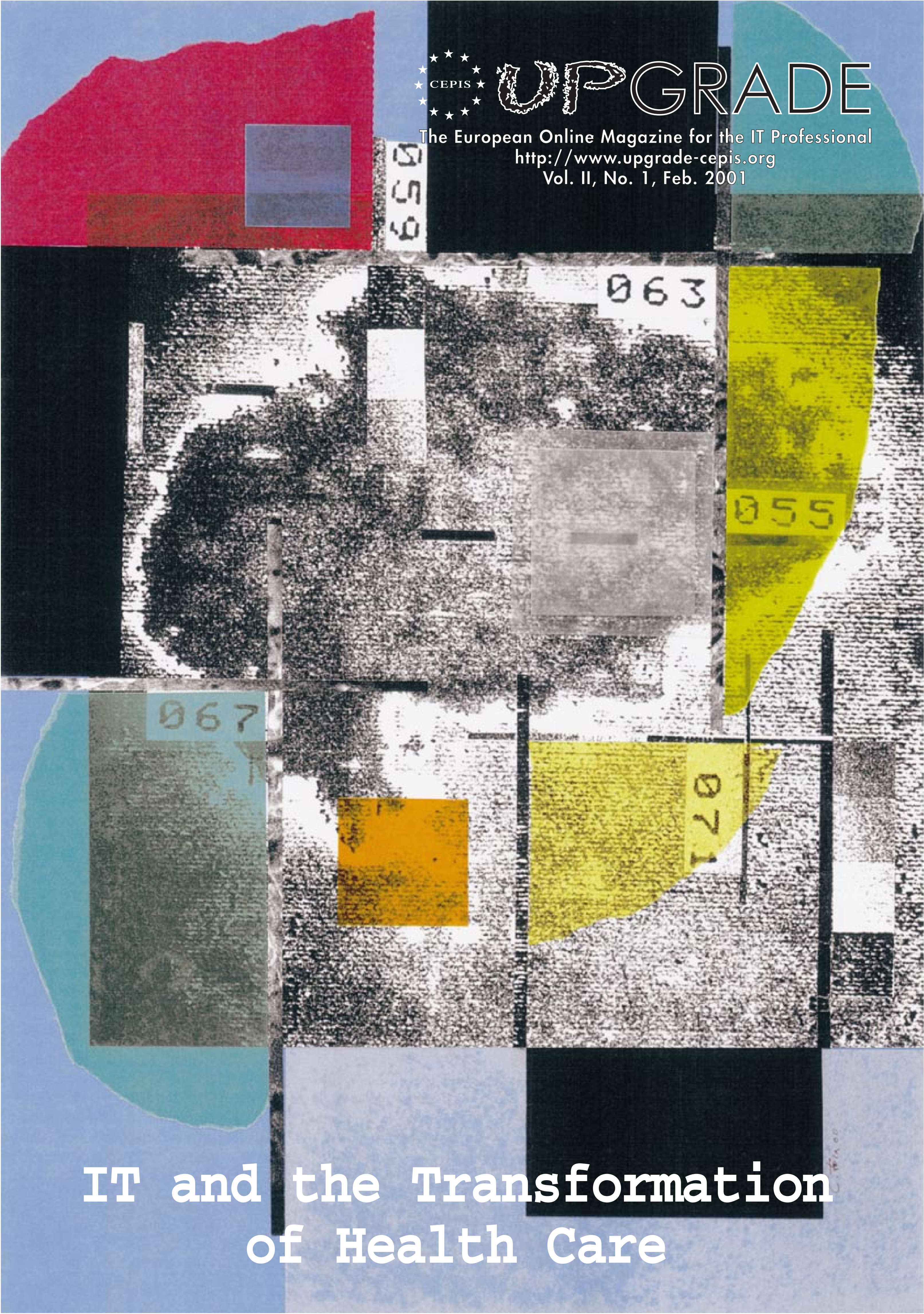
CEPIS UPGRADE
The European Online Magazine for the IT Professional
http://www.upgrade-cepis.org
Vol. II, No. 1, Feb. 2001



IT and the Transformation of Health Care

UPGRADE
The European Online Magazine for the IT Professional
http://www.upgrade-cepis.org
Vol. II, No.1, Feb. 2001

UPGRADE is the European Online Magazine for the Information Technology Professional, published bimonthly at http://www.upgrade-cepis.org/

Publisher
UPGRADE is published on behalf of CEPIS (Council of European Professional Informatics Societies, http://www.cepis.org/) by Novática (http://www.ati.es/novatica/) and Informatik/Informatique (http://www.svifsi.ch/revue/)

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IS and the Transformation of Health Care

Guest Editors: Stefan Klein and Valentín Masero Vargas

Joint issue with NOVÁTICA and INFORMATIK/INFORMATIQUE

Coming issue: "Visualisation of Software"

Editorial Note

Behind the Stage

When the Executive Committee of CEPIS gave their approval to the production of UPGRADE online magazine one of their requirements was that it *"shall not be an academic publication"*. The definition of *academic* in "The New Oxford Dictionary of English" is:

> **academic** adjective
> **1** of or relating to education and scholarship. • of or relating to an educational or scholarly institution or environment. • (of institution or a course of study) placing a greater emphasis on reading and study than on technical or practical work. • (of a person) interested in or excelling at scholarly pursuits and activities. • (of an art form) conventional, especially in an idealized or excessively formal way.
> **2** not of practical relevance; of only theoretical interest.

Therefore, if UPGRADE is *not* to be *academic* and not only of *theoretical interest*, then it must be of *practical relevance*. This is precisely the principal objective of UPGRADE and of its current partners, the magazines INFORMATIK/INFORMATIQUE and NOVÁTICA that achieve practical relevance not just theoretical interest by:

- The Editorial Boards of both NOVÁTICA and INFORMATIK/INFORMATIQUE advise the editors on the choice of IT-related topics.
- The editors appoint experts as guest editors who further define the concept and are able, through their reputation, to motivate first-class authors to submit papers of practical interest on the topic.
- In each issue a topic is covered with a number of papers. The authors and their papers are carefully chosen to cover a broad range of experience and to show different facets of the topic.
- Members of the editorial boards read and comment on submitted papers to ensure their practical relevance to our readers, which may lead the author to revise the paper.
- IT professionals with English as a first language then read and edit the papers, ensuring the texts are clear and understandable.
- Before publishing the papers are submitted to the authors for final approval, giving them a chance for ultimate corrections and amendments.

In this way we hope to contribute to the continued professional development of our readers, raising their knowledge to a higher standard.

We heartily thank all those who contribute, on a voluntary basis, to the high standard of our magazine: the guest editors, the authors, and the English editors.

Rafael Fernández Calvo** and **François Louis Nicolet

Presentation

IS and the Transformation of Health Care

Background

The health care industry in the industrial nations can be depicted as a complex network of players governed by various institutional regimes and regulations. Health care covers a significant – and rising – proportion of the GNP and it faces a financial crisis as the gap between the most advanced diagnostics and therapy concepts on the one side and resources for the provision of quality services for the general public on the other side is widening. As a result, governments, administrative bodies and the different players in the health care system are looking for innovative solutions to make health care services more effective and efficient. Given the information intensity of health care and the high degree of specialization and division of labour, information technology is seen as a crucial part of potential remedies.

While health care has been one of the application domains for the most advanced information and communication systems in areas like virtual reality, robotics, AI, ATM etc.(see e.g. Communications of the ACM, August 1997,40), the diffusion of IS throughout the industry, into ordinary hospitals, pharmacies and general practitioners offices, is lagging behind. In this issue we take a look into IS and the ongoing transformation of health care: How is IT used in response to the crisis in health care, does it facilitate and enable improved relationships among the different players in the industry? How is IS used to improve the quality of (everyday) health care provision on the one hand and the development of treatments on the other? The papers, which also illustrate the broad range of relevant IS domains, belong either to the field of research or to the field of specialized technical divulgation, and can be divided into three sections:

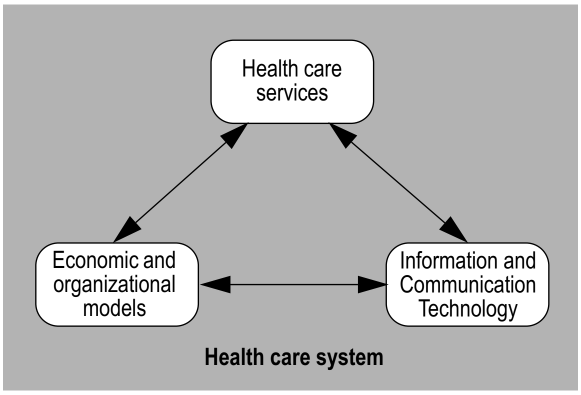

Figure 1: A triangle of transformations

(1) IS and the emergence of health care networks

In their paper, *Peterson, Smits and Spanjers* analyse three cases of health care networks. They use the conceptual framework of six dimensions ranging from strategic drivers to ICT infrastructure and network performance and the empirical evidence to propose design and success factors of ICT-enabled health care networks. *Gförer, Raupp and Schober* have scrutinized networks of cooperating physicians which have been regarded as a remedy for the German outpatient health care system. Their analysis shows that the viability of those networks depends on trust-building mechanisms and the application of fair profit allocation rules. They propose a systems architecture which reflects the specific requirements and success factors of cooperative doctors' networks.

Health care networks are also extremely useful for continuous education in the field of Medicine. *García Rojo* presents a state of the art report in which he describes the newest developments in medical education, pointing to some of the most interesting tools in this area, such as widely visited specialised websites or TIC applications for medical bibliography.

(2) Technological and Scientific Support

IT, along with scientific progress, are an important pillar for most of the changes that have been taking place in Health Care during the last years. One of the greatest changes enabled by IT has been Telemedicine. It enables health care professionals to collaborate with each other in order to provide better services to patients, such as diagnosis, treatment or even surgical interventions. *Masero Vargas, León Rojas, Moreno del Pozo and Silva Luengo* propose a system for improving Telediagnosis, based on anatomical three-dimensional anatomic reconstruction techniques.

Early Artificial Intelligence (AI) systems for medical purposes were developed for improving diagnostics too. *Barreiro, Crespo and Maojo* show a historical record of AI in the field of Health Care, from the latest applications to rather traditional ones such as expert systems, including image-based systems aimed at assisting in diagnosis, hospital information systems and decision support systems.

Based on an analysis of the clinical decision making process along the phases: diagnosis, prognosis and therapy, *Colloc and Bouzidi* have developed a decision support system which integrates sources such as patient data, expert knowledge, statistical and epidemiological data and previously stored experience and several decision paradigms.

One of the projects with highest impact, both on medical informatics and on public opinion is the Human Genome Project Speaking, due to the new fields that it opens and to the ethical conflicts that arise from it. *Martín Sánchez* gives an introduction into the field of Bioinformatics and shows its importance in this project.

The increased deployment of Internet services for the transfer of sensitive medical information has raised the awareness of security and data protection issues. *Ultes-Nitsche and Teufel* present a framework for secure access to medical data over the Internet. They focus on the problem of context dependent access control to support distributed clinical trials.

(3) Community health data

While most health care decision making is focused either on the patient, a type of disease or the health care providers, *Berndt, Hevner and Studnicki* describe a data warehousing approach to measure and assess the health status in local communities. Based on a complex framework of health status indicators from multiple data sources, they illustrate how data warehousing, OLAP and Internet services can be used to generate, interpret and distribute decision relevant data on a community level.

Stefan Klein *and* ***Valentín Masero****, Guest Editors*

Acknowledgements

The papers by García Rojo, by Barrero, Crespo and Maojo, and by Martín Sánchez are published by kind permission of BoleTIC, the magazine of ASTIC (Professional Association of IT Top Officials of the Spanish Public Administration). They have been selected amongst those that appeared in issue no. 16 (December 2000) of BoleTIC, dedicated to IT in Health Care, whose Guest Editor was Martín Sánchez, with the outstanding contribution of the Spanish Health Informatics Society (SEIS).

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Designing Electronic Network Organisations for ICT-Enabled Health Care Networks

Ryan R. Peterson, Martin Smits and Ronald Spanjers

This paper describes the design and development of electronic network organisations in health care. The strategic drivers, design and ICT infrastructure of electronic health care network are outlined. Based on an in-depth investigation of electronic health care networks, this paper summarises the main lessons learned and the critical success factors. The implications for research and directions for health care practice are discussed.

Keywords: Electronic Network Organisation, Health Care, Information and Communication Technology Infrastructure, Stakeholder Partnerships, Network Designs and Development Stages, Case Studies.

1 Introduction

The network economy is challenging traditional well-established health care institutions to develop new patient-oriented models and invest in information and communication technologies. Once a cottage industry[1] of physicians, hospitals, medical centres and consultants, health care is now experiencing the value of integrated services and the collaborative advantage of networking. Economic, social, political and technological forces have driven physicians, consultants, hospitals and medical centres to develop electronic networks relationships, and 'e-care' is rapidly becoming a norm of quality [Peterson/De Wit 99].

While much is presumed and predicted about electronic network organisations in Health Care, little empirical evidence exists as to their drivers, design and development, and even less directions exist for health care practitioners. Based on an in-depth investigation of electronic health care networks, this paper addresses these issues and provides several guidelines.

2 Framing Electronic Network Organisations

A network organisation is distinguished from a classical organisation by the intensity, density, multiplexity, and reciprocity of inter- and intra-organisational ties, and a shared value system defining stakeholder[2] roles, responsibilities and relationships. An electronic network organisation is characterised by non-hierarchical, long-term commitments; multiple distributed stakeholder roles and responsibilities; independent, yet interdependent decision-making; and an ICT-based network infrastructure [Ribbers/Smits 99].

1. Cottage industry: a business or manufacturing activity carried on in people's homes. *(ed.)*
2. Stakeholder: a person with an interest or concern in something. *(ed.)*

If electronic network organisations are going to proliferate and become the dominant organisation type on the emerging economic landscape, they must exhibit unique features that are particularly well adapted to the new environmental exigencies. Situational factors are described by the strategic drivers and enabling conditions, and the main network dimensions refer to the design and processes of the network organisation and ICT infrastructure (Figure 1).

The main dimensions of electronic network organisations are [Peterson et al. 00]:

- *Strategic drivers:* The network objectives and motives of organisations and stakeholders involved in the network.
- *Enabling conditions:* The conditions that enabled or stimulated the emergence and formation of the network.
- *Network Design:* The structuring of the network responsibilities, decision-making units, and coordination mechanisms

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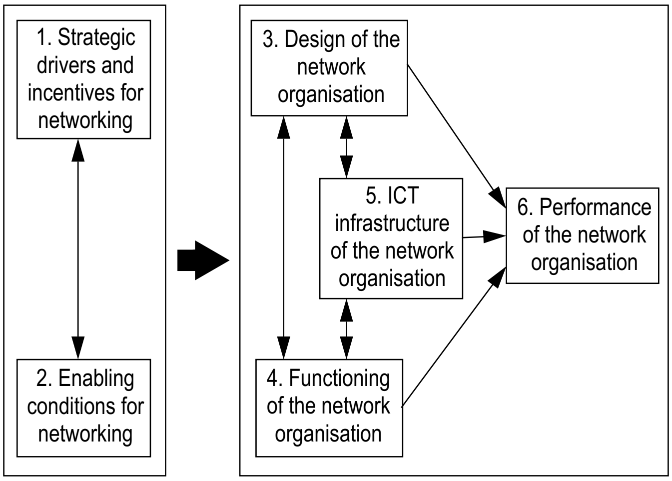

Fig. 1: Framing Electronic Network Organisations

- *Network Processes:* Network business activities and transactions.
- *Network ICT Infrastructure:* The reach, range, and standardisation of the ICT infrastructure.
- *Network Performance:* Organisational and ICT impacts and effects of the network.

3 Electronic Health Care Networks in Practice

In this paper we analyse three cases of electronic health care networks. The first two cases, the Roessingh Rheuma Network (RRN) and the Bosch Medicentre Network (BMN), are located in the Netherlands. The third case study, the Renal Telemedicine Network (RTN), is located in Australia. Summaries of the cases are presented in Table 1.

Bosch Medicentre Network

On the 6th of January 1990 the Willem-Alexander Ziekenhuis and the Groot Ziekengasthuis merged into the Bosch Medicentrum. The Bosch Medicentrum is a general hospital with a capacity of 780 clinical beds, 1,900 full time equivalents, 2,600 employees and 140 medical specialists. In seeking improved efficiency and effectiveness, the Bosch Medicentrum in 1996 started a reorganisation evolving from a facility management into a product-line management organisation structure.

Roessingh Rheuma Network

Roessingh Research and Development is a research unit of the Roessingh Concern and employs approximately 40 people. The Roessingh Concern has approximately 140 beds and approximately 40,000 rehabilitation treatments per year. It is one of the largest rehabilitation centres in the Netherlands. The Rheuma network was formed when a proposal was submitted to the Commission for Chronically Ill Patients to formalise and institutionalise communication lines between Medical Spectrum Twente (MST) and local clinics, and Leiden University Medical Centre (LUMC) and local clinics. This proposal was submitted in August 1998 and was a joint effort of both MST and LUMC.

Renal Telemedicine Network

The Queen Elizabeth Hospital (TQEH) provides a comprehensive range of specialist and diagnostic treatment services to the immediate community in western metropolitan Adelaide as well as country areas. TQEH's Renal Telemedicine Network (RTN) commenced in June 1994. Over 75% of patients are supported on haemodialysis and in South Australia the majority of these are located in "satellite" centres. Information and communication technology applications and infrastructure were installed at its four renal dialysis centres at TQEH Woodville and Wayville (10 km from Woodville) in September 1994, and at North Adelaide (8 km) and Port Augusta (300 km) in February 1995. RTN dialyses a total of 145 patients at these four centres, with each patient normally dialysing three times per week and attending an outpatients clinic once every two months. The network organisation also cares for 29 patients who dialyse at home.

4 Electronic Networks in Development

In general, the case studies provide ample evidence that electronic health care network organisations are in a constant flux, driven and enabled by both external opportunities and internal needs. The electronic health care networks come in different forms and shapes, and have different functions.

Electronic health care network organisations develop through different phases of maturity and networkability as they migrate and grow synergistically (Figure 2). However, while ICT enables the formation of professional networks in health care, it is ultimately the health care network partnerships that determine the direction and development of the network. Internal and external partnership building are especially important to the transformation of electronic network organisations in health care.

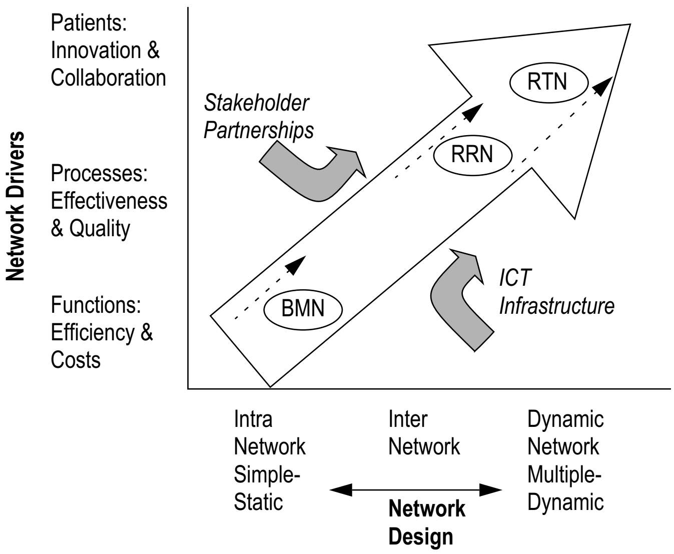

Fig. 2: Electronic Health Care Networks in Development.

Network Dimension	Bosch Medicentre Network	Roessingh Rheuma Network	Renal Telemedicine Network
Strategic drivers and incentives for networking	Reduce costs, improve efficiency, no loss of quality in hospital health care.	Improve efficiency and effectiveness of rheumatology services in order to meet patients' needs. Formalise communication and develop shared expertise.	Improve efficiency and effectiveness of renal dialysis services in order to meet patients' needs. Improve communication and educate specialists.
Enabling conditions for networking	*The evolution from a facility management into a product-line management organisation structure.* Efficient and effective control of hospital organisations depends on ability to determine the relation between input and output.	*The demand and supply mechanisms regarding rheumatology knowledge across the network.* The demand and supply mechanisms regarding ICT knowledge across the network. Partnership building	*The demand and supply mechanisms regarding renal dialysis services across the network.* The demand and supply mechanisms regarding telemedicine applications across the network. Management of change. Partnership building
Design of the network	*Intra-Network.* Hospital-personnel (2,600) and medical Specialists (140) work together to attend to the patients needs. Hospital middle management, functional operators and medical specialists and automation coordinator.	*Inter-Network.* Separate responsibilities for rheumatology services and ICT services. Different functional roles and levels: "sponsor", "network coordinator", "participants/ users". Health care participants	*Dynamic Network.* Separate responsibilities for renal dialysis services and telemedicine technology services. Different functional roles and levels: "sponsor", "network coordinator", "participants/ users", "technology integrator". Health Care and ICT participants
Functioning of the network	*Internal medical information support.* Technical support, implementation and central computing facilities are outsourced.	*Network and stakeholder management.* Provision of telerheumatology services across the network. Leveraging of rheumatology expertise across the network. Demand and supply of multimedia network technology.	*Network and stakeholder management.* Provision of renal dialyses services across the network. Leveraging of renal dialyses expertise across the network. Demand and supply of telemedicine technology.
Network ICT infrastructure	*Dependent view of ICT infrastructure.* HISCOM information systems are used. Low reach and range of infrastructure.	*Enabling view of ICT infrastructure.* Network standardisation. Moderate reach and range of infrastructure.	*Enabling view of ICT infrastructure.* Network standardisation and multi-tier architecture. High reach and range of infrastructure.
Performance of the network	*Reduced costs without loss of quality in hospital health care.* Networking is reaching beyond organisational boundaries in transmural care projects.	*Improvement of inter-institutional collaboration and communication.* ICT flexibility and reliability. Efficiency and effectiveness improvement of rheumatology services. Stakeholder satisfaction. Redefinition of stakeholder roles.	*Improvement of inter-institutional collaboration and communication.* ICT flexibility and reliability. Efficiency and effectiveness improvement of renal dialysis services. Stakeholder satisfaction. Institutionalisation and growth.

Table 1: Network dimensions and key findings.

Both the technical and the social infrastructure are important for the design and growth of electronic network organisations in health care. Moreover, network management, focusing on stakeholder partnerships and social coordination, is pivotal to the successful development of electronic health care networks [Peterson/De Wit 99], [Smits/Van der Pijl 99].

Based on our investigation, the following lessons and critical success factors are drawn on the drivers, design and performance of electronic health care networks:

- *Strategic Drivers*
  Strategic drivers for electronic network organisations are improvement of efficiency and cost-effectiveness, process quality and effectiveness, and primary care process for meeting patients' needs and patient-information-streams. However, these strategic drivers differ over time as electronic network organisations transform (see Figure 2). Different "rationalities" exist for improving the efficiency and effectiveness of health care services. From an internal perspective, inter-organisational collaboration and expertise development are emphasised. In the external environment, the will to meet patients' needs is underscored.

- *Enabling Conditions*
  The important lesson learned in all cases is the critical role played by management and the process of managing stakeholders' needs and expectations, and inter-organisational change. Managing the demand and supply of care and technology is a key enabler of network organisations in health care. On one hand, there is the need to share and collaboratively develop health care expertise. On the other, there is also the need to apply ICT to facilitate the efficient and effective delivery of health care services.
  Proper attention to organisational, political and human issues can not be overstated enough in the development of successful network organisations, especially in health care where professionals carry the "power to innovate". While ICT may provide the conditions for networking, it is the organisation, its professionals and management that ultimately drive networking. Attention for stakeholder motives and expectations is therefore critical.

- *Network Design*
  Regarding the design of network organisations in health care, the case studies cover a spectrum from inter-organisational (the RRN and RTN cases) to intra-organisational and (the BMCN case) network organisation (see Figure 2). Furthermore, each case covers a different phase of growth: piloting (the BMCN case), learning (the RRN case) and growing (the RTN case).
  Interesting is also the growth of ICT infrastructure reach and range during these different phases. This growth in ICT is readily recognised in the RRN and RTN cases in which telemedicine technologies are applied in more organisation functions as the network grows. During these phases, ICT applications are modified and redesigned to meet the needs of users and the different clinical, educational and administrative services. Flexible ICT infrastructures are therefore

required in developing dynamic electronic network organisations, driven by the need to innovate and collaborate to meet patient demands.

- *Network Processes and Functioning*
  In the functioning of network organisations in health care different processes are distinguished. Health care transactions, in the form of patient-information streams and clinical communication, between health care service providers are at the core of network processes. Network management and coordination are likewise important and organised through both formal and informal mechanisms in which key stakeholders take part.
  Important network coordination mechanisms include stakeholder committees, joint decision-making, informal and formal communication and stakeholder involvement. ICT-mediated coordination in the form of electronic databases and video conferencing are especially used in Inter Networks and Dynamic Networks.

- *Information and Communication Technology*
  With regard to the role and impact of ICT in electronic network organisations in health care, the case studies indicate that ICT plays an important role in each of the network dimensions as described above. However, it is the network constituency that needs to recognise, adopt, implement and exploit the potential opportunities provided by ICT. An "enabling view" of ICT is associated with a higher level of networkability. While ICT enables the formation of professional networks in health care, it is ultimately the health care network that drives and determines the acquisition and application of ICT in the network.
  The cases indicate that ICT requires constant modification to meet the specific needs of the health care network functions, and that the ICT supplier to the network organisation needs to be actively involved in the different stages of network formation and professionalization. The flexibility of ICT, expressed as the infrastructure reach and range, is important to the development of electronic network organisations. Equally important are the multi-tier architecture standards that need to be agreed upon by the different stakeholders.

- *Network Performance*
  The ability to describe and measure the performance of the network increases when a higher phase of growth has been reached. In the piloting phase, performance measures are described in general terms, repeating the mission statement. In the learning phase, performance is likewise described in general terms, with a focus on stakeholder expectations and networking agreements. Stakeholder roles are redefined and the performance is assessed in terms of stakeholder satisfaction. In the growing phase, stakeholder roles have been institutionalised and the "benefits" of networking become clear. These include health care efficiency and effectiveness gains, professionalization and expertise development, and stakeholder satisfaction.
  The financial performance of the network remains difficult because the relation between input and output in a health care organisation is hard to determine. Moreover, "traditional" cost-benefit analyses of network organisations in health care are sub-optimal because they fail to account for all the (inter-/intra-organisational) changes that occur as a result of networking.

5 Future Directions

As described in the foregoing sections, this investigation provides a number of lessons learned for designing electronic network organisations in health care. Electronic network organisations are in a constant flux, driven and enabled by external opportunities and internal needs, addressing both organisational and ICT infrastructures. As the network economy evolves and electronic network organisations transform, research is on-going in this field, and currently other cases in the health care sector are being studied in the second phase of a research programme on network organisations (see also http://nefeti.kub.nl).

As part of a long-term research programme on network organisations in health care, and other industries, our research endeavours are geared at:

- analysing and understanding emerging business models of network organisations, and the supporting and shaping role of ICT infrastructures and applications;
- providing directions and guidelines for developing and migrating towards network organisations, and the implications and requirements for ICT infrastructures.

In particular, future research is focused on identifying and explaining electronic network designs of high performance network organisations in different phases of development. Only then can we truly begin to understand the design and dynamics of electronic network organisations in a global network economy, and provide design tools for developing successful electronic network organisations.

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Strategies and IT Integration in Outpatient Doctors' Networks

Stefan G. Gfrörer, Markus Raupp and Franz Schober

We analyse doctors' networks particularly with a view on firm level network strategies and the supporting information technology integration. Our main conclusions are that the viability of doctors' networks critically depends on trust building mechanisms like the restriction of the network in size and complexity and the application of fair profit allocation rules. Concerning information technology the implementation and use of highly integrated inter-organizational systems appears most promising. We propose a system architecture that integrates information technology along the medical, the business and the communication systems dimension.

Keywords: Outpatient health care, cooperating physicians, doctors' network, integrated interorganizational information system.

1 Introduction

Because of its already very high and still increasing costs the German health care system has been under heavy debate during recent years. As about 60 percent of the overall health care costs are caused by outpatient health care, new and more efficient organizational solutions of outpatient health services have been searched for. One proposal that plays a major role in the current debate is the establishment of doctors' networks. In the meantime some pilot networks have been established in Germany [Kassenärztliche Bundesvereinigung 99], but it is too early to draw firm conclusions from these first experiences.

The German outpatient health care system is embedded into a strong regulatory framework. Important parties are the medical association ("Kassenärztliche Vereinigung"), and the statutory health insurance companies which are admitted to the system. The medical association has mainly two objectives: firstly to represent the interests of the member physicians in the society, and secondly to act as a clearing organization between physicians and insurance companies.

With more and more financial constraints on the statutory scheme, the system exhibits some serious deficiencies. As the total financial volume for redistribution to the physicians is fixed, the system invites for opportunistic behaviour on the doctors' side. This typically implicates a hidden, but nevertheless fierce competition between the physicians to increase the volume of services provided and in consequence jeopardizes the cost efficiency of the overall system [Milde 92].

Therefore, other solutions have been proposed. One of the proposals centres around the idea of doctors' networks, where several physicians from complementing disciplines establish a relatively stable and long-term cooperation. A core element of a doctors' network, hereby, is the joint treatment of a patient by several legally independent network members for a lump fee which has to be allocated to the treating physicians by some network-internal mechanism. In this sense a doctors' network is quite distinct from and goes far beyond other forms of cooperation between physicians [Schober/Gfrörer]. The lump fees are negotiated between the doctors' network and the medical association or even directly with some or all of the statutory insurance companies on a case-specific as well as a network-specific level, which is possible in Germany since 1st January 2000.

While the doctors' network approach would reduce the problem of opportunistic behaviour in the current system, it poses new problems. One is the potential rivalry between the doctors within a given network that would transport the problem of opportunistic behaviour only to another level. A second question concerns the competition between networks and the creation of competitive advantages of one network against rival networks. Thirdly, and most importantly, the network approach must be accepted by the patient, i.e. must be more attractive than the current situation with individually operating physicians. Besides many other factors, the solution to the three problems is also impacted by the proper use of information technology in a doctors' network. As we will argue, a common and highly integrated inter-organizational information system (IOS) constitutes an important strategic resource that helps to

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add value to the services rendered to the patient, to keep cost under control and to position the network against rival networks.

The aim of our paper is to evaluate the key factors that are critical for the success of doctors' networks both from a strategic and information technology (IT) perspective. In chapter 2 we apply a strategic framework, that we have developed for the analysis of different types of networks in general [Raupp/Schober 00], to evaluate firm-level strategies of physicians participating in doctors' networks. Chapter 3 deals with the role of IT more specifically, and proposes an overall architecture for an IOS in doctors' networks. Chapter 4 concludes with a summary and open questions for further analysis.

2 Strategies in Doctors' Networks

2.1 General conditions for strategy definition in networks

The viability and success of any network arrangement essentially depends on the individual contributions to the overall objectives of the network, respectively on the investments of each network member. Bargaining power exploitation by some participants in order to proactively influence the individually appropriable profit shares can negatively impact the investment incentives of the other network members and in consequence can compromise the overall efficiency of the network arrangement [Schober 99]. It is therefore important to classify different network arrangements contingent to their inherent bargaining power properties. Following [Raupp/Schober 00] networks and their inherent bargaining power distribution can be characterized by network size and network topology. These dimensions essentially determine the necessary degree of formalization in the underlying network coordination structure, which itself is primarily determined by means of explicit or even implicit contractual specifications. Joint investment plans for IOS as well as plans for an inter-organizational process integration constitute important parameters of the network coordination structure [Raupp/Schober 00].

Network size describes the number of members of a network. Network topology is determined by the distribution of economic linkages between the network members. In symmetric networks most members interact with each other, either directly or via a joint activity such as a professional association. A typical example for a symmetric network arrangement is the medical association, which coordinates some common interests for its members. In asymmetric arrangements, there exist some network members which have significantly more bilateral linkages than others, like in buyer-supplier networks where some buyers do business with several suppliers, and where little interaction occurs between the suppliers.

By means of cooperative game theory it can be shown, that in symmetric network arrangements bargaining power imbalances decrease with increasing network size. In contrast, in asymmetric arrangements bargaining power imbalances intensify with increasing network size [Raupp/Schober 00].

Comparable to buyer-supplier networks also doctors' networks may exhibit substantial asymmetries in bargaining power, particularly if some network participants take a gatekeeper's role as it is designated in the German proposal [Gfrörer et al. 00]. Asymmetric arrangements like doctors' networks are much more prone to opportunistic exploitation of bargaining power, trust exposure, and the corresponding negative impacts on investment propensities and the total network efficiency.

In the following we will focus our analysis on doctors' networks where gatekeepers take the role of network coordinators and represent the network as a whole against the external environment (e.g. patients, the medical association, or the insurance companies). Typical tasks of gatekeepers are the negotiation of case-specific or network-specific lump fees with the medical association or directly with the insurance companies as well as the routing of patients through the network. Gatekeepers are usually represented by highly reputable general practitioners. Obviously, because of the resulting information asymmetries these actors exhibit a dominant bargaining position in doctors' networks. Nevertheless, the participating physicians are not direct competitors but possess complementary skills and aim to cooperate on a stable and long-term basis. Furthermore, these arrangements include common investment strategies, e.g. into sophisticated medical technologies, but also into proprietary and highly integrated IOS to gain sustainable competitive advantages against rival networks. Because of these characteristics it is almost impossible to institutionalize a network coordination structure on basis of *ex ante*[1] specified contracts and rules. In consequence of the incompleteness of contracts and the asymmetric distribution of bargaining power, doctors' networks require trust-building mechanisms to ensure the long-term viability of the arrangement [Gfrörer et al. 00]. These mechanisms are strongly related with the firm-level network strategies and will be discussed in more detail in the following chapter.

2.2 Firm-level network strategies

Firm-level network strategies, i.e. in our specific context the strategies of each individual physician participating in a network arrangement, are an integral part of the overall business strategy and concentrate on the positioning of each member *vis-a-vis* the other network members. It is important, that the firm-level strategies fit with the objectives on the overall network-level respectively with the coordination structure of the underlying type of network arrangement.

Firm-level network strategies comprise two dimensions: profit sharing strategies and resource sharing strategies [Raupp/Schober 00]. Both dimensions can adopt either a competitive or a cooperative connotation. Profit sharing strategies are concerned with the allocation of revenues, investments, and costs and depend on the strategically motivated application of bargaining power. Competitive profit sharing strategies are characterized by a full exploitation of bargaining power while cooperative profit sharing behaviour comprises limitations of bargaining power exploitation, for example, by means of an *ex ante* implementation of fair profit allocation rules including fair sharing of joint investments [Schober 99] or an *ex ante* restric-

1. *ex ante*: based on forecasts rather than actual results.

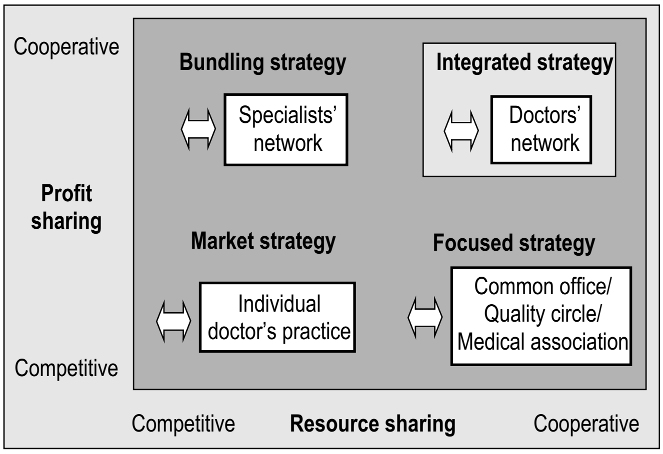

Fig. 1: Typology of firm-level network strategies.

tion of the network size. The resource sharing strategy focuses on the management of resource positions in inter-organizational arrangements. Cooperative resource sharing strategies focus on the creation of joint network specific competencies whereas competitive resource strategies strictly emphasize the protection of core competencies for each network member.

Based on the cross comparison along the cooperative respectively competitive orientation of the two strategic dimensions four distinctive categories of firm-level network strategies can be distinguished: integrated strategy, focused strategy, bundling strategy, and market strategy. They correspond with different types of possible network arrangements, see Fig. 1.

Physicians participating in a doctors' network can benefit from a mix of cooperative resource sharing strategies and cooperative profit sharing strategies [Gfrörer et al. 00]. Pooling of medical core competencies and patient information hand in hand with joint investment into medical technology and integrated IOS constitute central objectives of a doctors' network. Chapter 3 will discuss the aspect of IOS integration in doctors' networks in more detail. Furthermore, the creation and nurturing of social and managerial network competencies including the ability to develop trust, to share risk and to enhance collective learning are of central importance. Typically, a key strategic asset in doctors' networks stems from the high degree of inter-organizational process integration. The productivity of an individual doctor in the network and the investment incentives of the other network members are reciprocally dependent. As a consequence, cooperative profit allocation strategies to strengthen mutual trust and investment incentives are critical for the long-term viability of doctors' networks. Trust building requires a renunciation of bargaining power exploitation by dominant network members, particularly on the side of the gatekeeper. The restriction of overlapping competencies in doctors' networks hand in hand with the *ex ante* limitation of the network size constitute important trust-building mechanisms. If asymmetric bargaining power is preserved, the weaker partners tend to underinvest and the resulting economic position is worse for all actors in the network [Schober 99].

In contrast, physicians participating in a "common office", a "quality circle" or in the "medical association" are typically characterized by "focused strategies". Apart from fundamental differences between these types of networks, in all arrangements the participating physicians primarily concentrate on the cooperation in a very specific domain of interest. In all other domains the physicians remain competitors, i.e. operate independently with individually owned patients and individual service provisions. Common office arrangements share mainly physical resources, whereas quality circles and the medical association focus on the sharing of information resources [Schober/Gfrörer]. In the latter case the cooperative resource sharing particularly focuses on data aggregation and fee settlement. But because of the competitive nature of all three types of network arrangements, the resource sharing is typically restricted to distinct domains of inter-organizational collaboration. Furthermore, the inherent competitive elements induce low incentives for joint investments into integrated IOS. Therefore, in these arrangements voluntary constraints on bargaining power exploitation typically are not required and consequently also trust-building mechanisms play a less important role.

"Bundling strategies" are especially suited for networks cooperating on a temporary basis. They apply to physicians who do not cooperate within the network on a permanent base, particularly to highly specialized physicians whose services are purchased by a doctors' network on demand (specialists' networks). Since there are no incentives for resource sharing in this case, we also would not assume joint investments into highly integrated IOS.

In our specific context, the "market strategy" and the related organizational arrangement "individual doctor's practice" do not reflect a network arrangement but serve as reference points in our framework.

With the emphasis on trust-building mechanisms, on a high degree of IOS integration and on the creation of a network-specific knowledge base, doctors' networks stand in sharp contrast to the other forms of cooperative doctors' arrangements [Gfrörer et al. 00], [Schober/Gfrörer].

3 IT Integration in Doctors' Networks

The knowledge about the patient and his or her treatment constitutes an essential competitive asset of a physician. This knowledge resides not only in explicit patient records, but also in implicit or "tacit" knowledge about each individual diagnostic and therapeutic case. Tacit knowledge cannot be codified and therefore also not transferred to other physicians except if they work very closely together. Here we see an immense source of enduring competitive advantage for doctors' networks. Sharing of knowledge and collective learning are key characteristics in doctors' networks. Because of its limited transferability, this knowledge base constitutes a barrier for patients to move to other networks or physicians outside the network, even if explicit medical records would be transferred.

Because of the tacit component, knowledge in a doctors' network cannot be represented by electronic patient records and IT-based applications as such. Yet, IT can significantly enhance the knowledge creation process even on the tacit level [Schober 00]. In addition, IT can also help to improve the economic efficiency of a doctors' network.

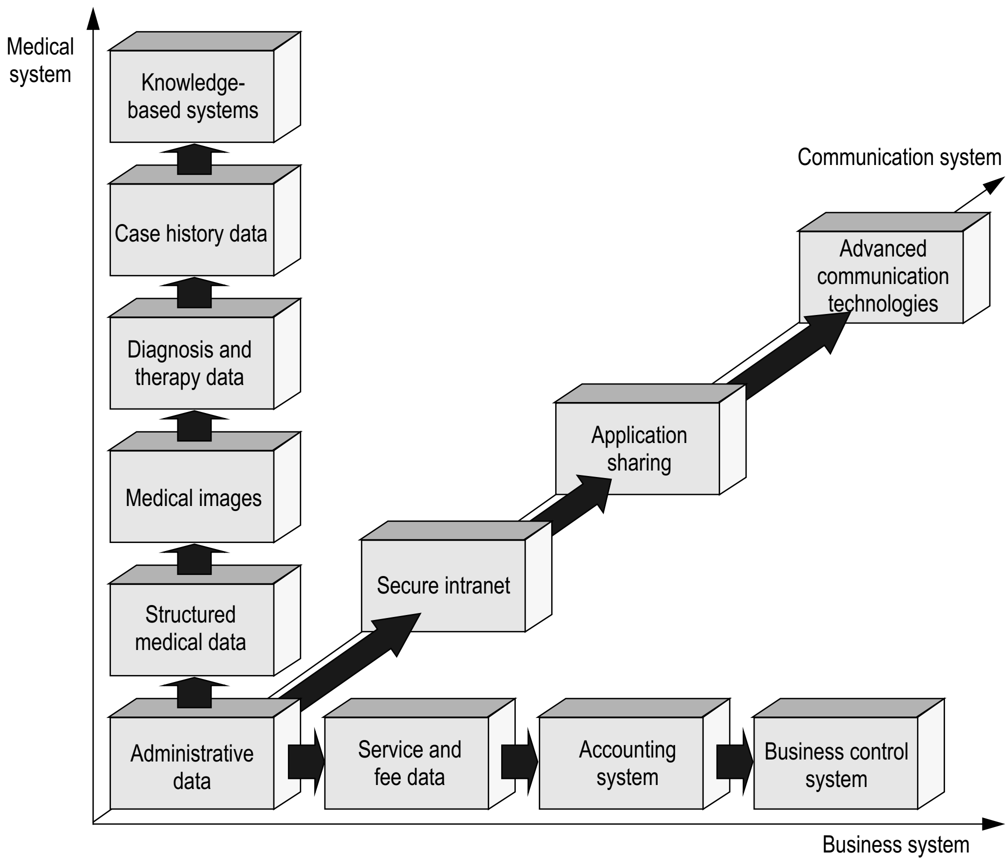

Fig. 2: Architecture of an integrated IOS.

In the following we propose an architecture for an integrated and IT-based inter-organizational system (IOS) for doctors' networks which supports both the knowledge creation process as well as the search of economic efficiency. Fig. 2 gives an overview of the IOS architecture. It is characterized by step-wise system integration along three dimensions: integration of the medical system, integration of the business system and integration of the communication system.

The core of each dimension of integration is a shared database with administrative data, e.g. general patient data or general data of the participating physicians including specific competencies and installed medical technologies. This administrative database is shared by all other applications along the three dimensions of integration.

Along the dimension of integration for the medical system we successively add structured medical data including laboratory measurements, images (e.g. roentgen or tomographic images), data on diagnosis and therapy and on patient case history. The highest integration level of the medical system refers to knowledge-based systems which support the physician in diagnosis and therapy. Although the intensively discussed medical expert systems have not found wide appreciation in practice there exists a promising application potential for intelligent checklists or for the use of case-based reasoning in comparing an actual diagnostic with previous cases of other patients. However, unstructured elements in the electronic patient record (e.g. dictated or written reports) raise several problems in data communication, data management and data administration. Therefore, metadata technologies that address the management of large bodies of text and facilitate the discovery and interconnection of similar medical cases play an important role [Panko et al. 99]. The extraction of case history data represents a task far beyond the capability of administrative database systems. This implies to build up an extensive and formalized case history which certainly would constitute a major competitive advantage of a doctors' network.

The integration along the dimension of the business system starts with the compilation of network-specific lists for available services and fees based on elementary settlement runs. A more sophisticated common accounting system represents a next step of integration. It would contain all important business data like investments into medical, office or information technology, salaries, material costs, and purchases from services outside the network. The accounting module should also include an accepted algorithm for redistribution of fees between different service providers in the network and the calculation of the overall remuneration for each physician. The accounting system will ultimately serve as the basis for a common business control system which provides and compares various indicators to measure the economic efficiency of the network. The business control system requires also a tight link to the medical system, particularly to deliver specific indicators like cost by disease or treatment categories.

A key element of the integration along the dimension of the communication system is system security, particularly because of the sensitivity of patient data. System security comprises the control of access rights (which are basically at the patient's side and have to be verified by the patient) and the secure encryption of data, preferably already in the database but in any case when passing through public networks. Application sharing allows several physicians to share the same application. This is particularly important for the update and retrieval of patient data, but also for most of the other applications in the IOS, e.g. certain knowledge-based systems for diagnosis support. Architecture-independent Java applets coupled with mark-up languages (SGML and its subset XML) represent cost-efficient options to work simultaneously at different locations with one set of data and applications [Panko et al. 99]. Advanced communication technologies such as video-conferencing improve the real-time communication between the doctors in the network. The use of e-mail and the World-Wide Web may also serve as a platform for communicating directly with the patients, hospitals and other third parties.

The IOS components in Fig. 2 are certainly far from being complete and should only give some important directions of integration. Nevertheless, a high degree of IOS integration along the medical, business, and communication dimensions surely is a necessary prerequisite for knowledge creation in tightly coupled doctors' networks, but by itself it is not a sufficient condition. Social and managerial network competencies including capabilities for conflict resolution and trust building represent further flanking mechanisms for efficient knowledge creation in doctors' networks.

4 Summary and Conclusion

Within this paper we have analysed two critical dimensions for the success and the long-term viability of doctor's networks: cooperative resource and profit sharing behaviour on the firm-level on the one hand and a high degree of process and IOS integration on the other hand. The latter aspect essentially requires shared goals between the participating physicians that are embedded in a trust-based overall network coordination structure.

We have identified doctors' networks as arrangements that are exposed to bargaining power asymmetries and therefore require the institutionalization of trust-building mechanisms. These include the restriction of the size and complexity of the network as well as fair rules for fee, investment, and cost allocation. The restriction in size contradicts with the configuration of the current pilot networks in Germany which seem to be quite large [Kassenärztliche Bundesvereinigung 99]. Furthermore, the pilot networks seem to involve overlapping competencies of the participating physicians [Kassenärztliche Bundesvereinigung 99], a central inhibitor of trust-building in network arrangements.

Concerning inter-organizational information technology we have voted for several reasons for a highly integrated solution. One reason stems from the long-term nature of the cooperation and the importance of trust. The second reason relates to the sharing of common resources as one important objective of doctors' networks. Integrated IOS make this sharing more efficient. Another reason is the creation of a knowledge base. A fourth reason, finally, concerns the patient. Only a highly integrated IOS provides the necessary integrity in the sense that it presents the network to the patient as one entity rather than a collection of more or less independent physicians.

Our analysis leaves a series of questions open. One is the coexistence of individual physicians and physicians organized in networks. Another open question concerns the cooperation between doctors' networks, hospitals, and highly specialized physicians. Also cooperative arrangements between doctors' networks and insurance companies constitute a topic for further investigation. Some legal aspects were touched only very briefly, particularly the sensitive question of patient data protection. Therefore, much research in the area of network organizations in health care is still needed.

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Continuing Medical Education and Professional Development

Marcial García Rojo

This article reviews the goals of medical education, that must be redefined broadly due to the presence of new scenarios, where new approaches, such as the implementation of logical reasoning process, have to be contemplated. We describe how this can be achieved through the use of Internet and other authoring tools. Evidence-based medicine is essential when physicians are dealing with literature. Frequency of use of Internet and the quality of the information are analysed. In a second part, we review the advantages and disadvantages of virtual congresses, and the impact of new technology terminology in medical literature. In a near future, the use of medical integrated workstations will be common; they will allow fast and efficient information searches, and they will be essential to access patient previous history, related cases, or finding the best choice of treatment.

Keywords: Continuing Medical Education, Medical Informatics, Internet, Evidence-Based Medicine, Quality of Information.

1 Introduction

Continuing medical education (CME) is part of the process of lifelong learning that all physicians undertake. It has traditionally been viewed by the medical profession in terms of updating their knowledge. Nowadays, in order to practise effectively in the modern National Health System, doctors need skills that extend their medical knowledge beyond updating. Thus, hospital doctors and general practitioners have now accepted responsibility for both continuing medical education and professional development (CPD).

Similarly to other professional environments, medical knowledge, necessary for teaching or education purposes, is usually stored in computerized system. This process has been possible with the advent of electronic versions of specialized journals, congress proceedings on CD-ROM, the development of authoring tools with multimedia support (e.g. anatomy atlas, or diagnosis support expert systems). Certainly, the most important extension of medical informatics, since it appeared at the end of 70s, has occurred with the use of the Internet, with its useful hypertext text links in web pages, that allow easy development and dissemination of information integrating text, pictures, video, sounds, etc.

Thus, the rapid popularity of the World-Wide Web has changed the ability of medical doctors and patients to access a vast amount of information. At the same time, there is also a fast advance in basic and clinical sciences, diagnostics and therapeutics techniques, which professionals need to integrate into their daily medical practice.

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1960s: Research Systems (ECG, diagnosis).
1970s: Management, department, image (TC Scan), Mycin.
1980s: Reports, outpatients, Clinical I.S. and databases, artificial intelligence.
1990s: Integration, communication, vocabulary, evaluation

Table 1: History of Main Efforts in Health Informatics

As shown in table 1, that summarizes the historical evolution of applications in health informatics, main efforts were initially directed, with limited success, towards management process or experimental expert systems instead of towards solutions for education of health professionals.

This evolution did not correspond with the real needs of medicine professionals, who are usually closer to current Internet solutions developed by universities, pharmaceutical companies and communication companies, amongst others, that offer free access to updated information, including tools for search of medical articles (available or not in Medline), experts consultation, and so on.

[Collen 94] summarizes in the following points the reasons for the delay in the use of digital computers in the practice of clinical medicine :

1. There was a 10 years delay in information technology in health systems
2. It is a complex environment where simple solutions, like those in bank companies, are not applicable
3. The need of technology able to manage complex information (QMR or Dxplain)
4. Inertia, the fear of pre-established rules

The increasing interest in new information technologies amongst medical professionals, in parallel to the extensive use of the Internet, can be corroborated by Health on the Net (http:/

• National Library Medicine, Medline	http://nml.nih.gov/
• British Medical Journal (BMJ)	http://www.bmj.com
• Medscape	http://www.medscape.com/
• Intelihealth	http://www.intelihealth.com/
• Mayo Health System	http://www.intelihealth.com/
• Mayo Health System	http://www.mayohealth.org/
• Health On the Net	http://www.hon.ch/
• The Lancet	http://www.thelancet.com/

Table 2: Most frequently requested web sites by doctors in 1999.

/www.hon.ch) surveys, that show how, in Europe, in 1999, 46% of doctors were Internet users, and, although 95% of them evaluate as useful the information available in Internet, a 7% of expert users consider that this information should improve greatly.

These surveys also show the most popular web sites in the medical community, that are shown in table 2. It is obvious that sites offering biomedical information (electronic versions of traditional medical journals and Internet servers containing information about diseases) were the most requested in 1999.

The noticeable increase of papers related to information technology, together with the increasing presence of medical journals in Internet, has significantly expanded the interest in this area amongst health professionals [LaPorte et al. 95].

Using multimedia techniques in Internet, the University of Sydney has achieved a 100% use of these technologies by medical students, comparing with a 25% of students using them at the beginning of 90s [Kidd et al. 93].

This paper focuses on the different solutions of continuing education directed to current practitioners who generally have not received any specific training in information techniques. Although this technology is being simplified, most authors agree to include a postgraduate programme in medical informatics in order to obtain an efficient use [Coiera 98].

Every effort in continuing medical education should be preceded by the evaluation of the cognitive process (reasoning and decision making), instead of creating a simple data collection with the classical textbook format [Patel et al. 00].

[Coiera 98] proposes the following Decalogue of essential clinical informatics skills:

1. *Understand the dynamic and uncertain nature of medical knowledge, and be able to keep personal knowledge and skills up-to-date*
2. *Know how to search for and assess knowledge according to the statistical basis of scientific evidence*
3. *Understand some of the logical and statistical models of the diagnostic process*
4. *Interpret uncertain clinical data and deal with trial and error*
5. *Structure and analyse clinical decisions in terms of risks and benefits*
6. *Apply and adapt clinical knowledge to the individual circumstances of patients*
7. *Access, assess, select and apply treatment guidelines, adapt them to local circumstances, and communicate and record variations in the treatment plan and outcome*
8. *Structure and record clinical data in a way appropriate for immediate clinical tasks, for communication with colleagues, or for epidemiological purposes*
9. *Select and operate the most appropriate communication method for a given task (e.g., face-to-face conversation, telephone, e-mail, video, voice-mail, letter)*
10. *Structure and communicate messages in a manner most suited to the recipient, task and chosen communication medium.*

In 1996, the percentage of Spanish doctors using computers was below 40%, a figure similar to those observed in France or Portugal, but considerably lower than the 80% observed in British or German practitioners [Ceusters/Prorec-Be 98].

2 New goals in education

[Ludvigsson 99] has proposed the following guidelines to redefine the goals of medical education:

- *Understanding biomedical concepts related to disease mechanisms The Flexnerian or "reductionist" model of teaching, where the body is considered as a machine with organs that can be repaired by specialists in that specific system, should be avoided.*
- *Developing interpersonal and hands-on skills, including forming productive partnerships with patients and health care team members, and demonstrating appropriate professional values.*
- *Applying a logical reasoning process to solve individual or community problems and to critically review new information.*
- *Accessing information resources appropriately to support high quality practice.*

New technologies allow students to proceed at their own pace and create flexible learning environments. Advanced web technology allows programmed access to learning modules and tests. "Virtual" tutorials are conducted by threaded discussion groups. These methods hold great promise for allowing lifelong learning through accessing up to date electronic knowledge resources on the web and CD ROMs [Neame et al. 99].

In addition, during their clinical years, students can use web based technologies for keeping a learning log to record their studies and to accumulate a personal log of cases or problems seen, procedures watched or undertaken, and skills acquired for certification purposes a system often described as portfolio based learning [Snadden 99].

3 Authoring tools

In this section we have grouped together those solutions implemented with conventional programming languages (C++, VisualBasic, Delphi, etc.) that usually need an installation process in each computer. In medical informatics there has been a noticeable predominance of Mumps and Open M languages.

GROUP	
Clinical history:	61
Information systems	16
Dentistry	10
Radiology (Reports and Imaging)	8
Medical office	6
Clinical laboratory	4
Anatomic pathology	4
Cardiovascular	3
Other specialities	10
Management	13
Education	4
Anatomic or diseases atlases	2
Medical literature	2

Table 3: Medicine software available in 1997

These tools are used for education programs in specific areas, protocol guided systems, or computerised physician decision support.

For instance, StrokeNet was developed to simplify emergency attention for strokes, through a recompilation, on one hand, of present symptoms and signs, and on the other hand, by generating diagnostic and therapeutical recommendations based on the most recent research studies [Moehr 00].

In the last few years these tools have been integrated into the so-called groupware applications, such as Lotus Notes. These allow a direct link between the student and the professor, as well as numerous utilities, like discussion forums with the simultaneous interaction of multiple students.

Therefore, this kind of solution will probably be integrated in health networks and information systems in primary care and hospital services, as additional and supplementary components of Internet technology. An example of this integration can be observed in the projects included in HealthNet, in Canada, that since 1996, has developed medical informatics projects, including collaboration programs between different participating groups.

[Keravnou et al. 97] have grouped intelligent medical systems into:

- ***Protocols and guidelines:*** *protocols for medical procedures and therapies, clinical guidelines, health care processes;*
- ***Automatic diagnosing and decision support tools:*** *knowledge acquisition and learning, decision support theories, diagnostic problem solving, probabilistic models and fuzzy logic;*
- ***Temporal Reasoning and Planning:*** *planning and optimising of therapies, patients management, global health care planning, planning environments;*
- ***Natural language and terminology:*** *medical dictionaries, automatic abstracting, information retrieval, communication, multilingual dictionaries, lexicons;*
- ***Image and signal processing:*** *image interpretation, pattern recognition and identification;*

We have collected a list of 78 commercial professional health programs, distributed throughout Spain in 1997. Only 4 programs (5%) were related to continuing medical education (table 3).Campbell and Johnson conducted a Medline search, collecting all available abstracts of articles addressing multimedia computer aided learning (n=258) and multiprofessional learning (n=92) written in 1985–98. They conclude that most publications (63%) in Medline that represent multimedia computer aided learning are project descriptions or position statements, rather than reports of research (34%) including qualitative or quantitative methods used to systematically investigate the topics. Furthermore, references to established educational principles were infrequent (24%) and few abstracts (7%) referred to educational theory. Research is dominated by quantitative methods of questionable validity and utility. Relevance to practice is centred on teaching, but with minimal consideration of established educational principles or theories [Campbell/Johnson 99].

4 Evidence-Based Medicine

Evidence-Based Medicine (EBM) is supported by three main pillars: a) the proliferation of clinical research projects related to new technologies, above all, drugs; b) the development of clinical research methods; and c) the important increase in clinical documentation. In summary, it deals with all medical literature [Marimón 99].

Therefore, the main goal in EBM is the conscious, explicit and judicious use of the best evidence available to support clinical decisions in patient care. In other words, considering relevant clinical investigations, including precision and accuracy in diagnostic tests, prognostic markers influence, and efficiency and security in therapeutic, rehabilitating, and preventive measures [Bravo Toledo 00].

Available evidence search tools are, on one hand, secondary (filtered) sources, such as briefing journals with critical reviews (e.g. Evidence-Based Medicine journal, edited by the American College of Physicians, with publications in Internal Medicine, Primary Care, Paediatrics, Surgery, Psychiatry, Obstetrics and Gynaecology), the Journal Clubs (e.g. ACP Journal Cub), CAT bank (Critical Appraisal Topics http://cebm.jr2.ox.ac.uk/docs/catbank.html), and resources to find the former (such as Bandolera, also available in Spanish at http://www.infodoctor.org/bandolera/); on the other hand, specialized database such as Cochrane Library.

Although evidence-based medicine requires new skills from physicians, including searching literature, new technologies use should be evaluated prudently. [Verhoeven et al. 00] performed a randomised comparative study to determine which literature retrieving method is most effective for general practitioners (GPs): the printed Index Medicus; Medline through Grateful Med; or Medline on CD-ROM. They observed that in the period 1994–1997, the printed Index Medicus was the most effective literature retrieval method for GPs. For inexperienced GPs, there is a need for training in electronic literature retrieval methods [Verhoeven et al. 00].

5 Internet

The Internet has become an essential resource in continuing medical education. The main services we can find on the Internet, suitable for continuing education, are virtual congresses, specialized courses, clinical cases, virtual patients, discussion forms, or literature revisions, among others.

Most of these services are free and available to general public, if not already dedicated to a restricted professional group. They can be published to inform other people about the institution's activities or to record scientific meetings, even those not related to the Internet.

Frequency of use

An interesting study was done in Norway, at the end of 1998, analysing physicians' continuing medical education and their information-seeking behaviour, including their use of the Internet. 72% of Norwegian doctors had Internet access and 24% had access either at work, at home or both. Doctors with access both at work and at home used the Internet significantly more often and found it of greater professional value than did the other groups. A smaller proportion of general practitioners, compared to other groups in the profession, had access to the Internet. About half (48%) of Norwegian doctors use the Internet in a professional context. Research-oriented, male doctors, 30–49 years old, indicated the highest activity on the net. Authors conclude that, for the time being, it appears that the net widens the gap between doctors who actively seek new professional knowledge and those who do not [Nylenna 99].

Quality of Information in Internet

[Sandvik 99] evaluated the Internet as a source of information about urinary incontinence. 75 web sites providing interactive information about incontinence were analysed, along with 25 web doctors, and two news groups. Popularity indexes were measured using Hotbot and Altavista indices, according to number of links to web sites. Excellent information about urinary incontinence was found on the Internet, but the number of links to a site did not reflect the contents quality. Patients may get valuable advice and comfort from using interactive services. Well known organisations (societies, foundations, and journals) will probably offer better information than universities, hospitals, and clinics (labelled "professionals") and "commercial" sites.

In English-speaking countries, professional colleges (like royal colleges in U.K.) are responsible for providing a framework for continuing professional development; setting educational standards; and monitoring, facilitating, and evaluating activities for their members [du Boulay 00]. In Spain, this area is not well structured, and it is usually not well coordinated by

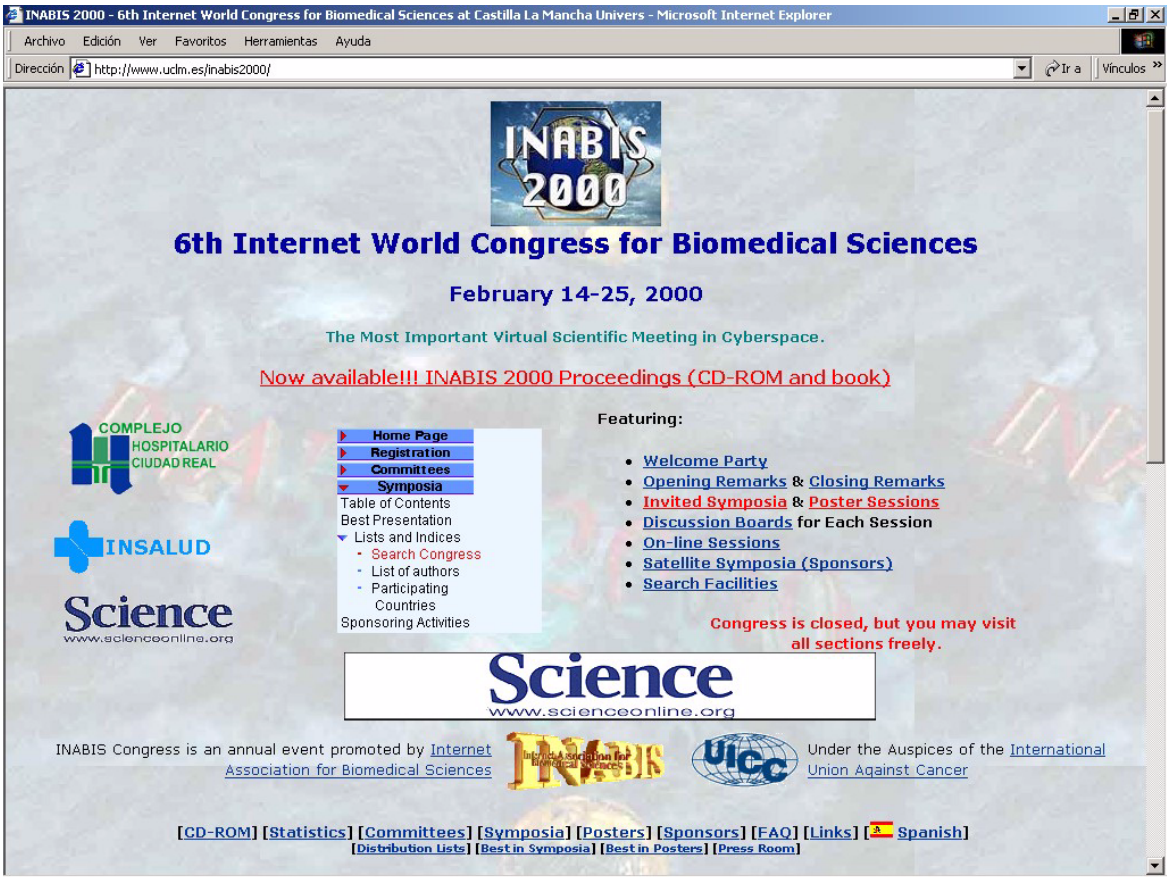

Fig. 1: World on-line congress INABIS 2000

They present larger opportunities to meet new colleagues with common interests
The ability to promote professional relationships even when congress is over
The ability to publish worldwide information about the city or institution where event is organized
The lower costs of organization
The avoidance of registration and accommodation costs
The automated evaluation of abstracts (via web or e-mail)
The easy coordination of efforts of multiple organising societies
Presentations can be directly modified by the authors
The unlimited number of scientific papers
The unlimited number of registered delegates or visitors
The information is available for an unlimited period of time
Efficient search facilities available
Active phase can be as long as needed

Table 4: Advantages of Virtual Congresses

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Scarce interest of commercial drug companies in sponsorships
Slow connections to the Internet
Little active participation in discussion forums
Specialized Internet programmers needed
Some scientific journals does not admit presentations previously published on the Internet

Table 5: Disadvantages of Virtual Congresses

Year	CME Search	MeSH Search
1991	369	54
1992	357	43
1993	385	41
1994	405	77
1995	462	91
1996	474	108
1997	541	118
1998	539	120
1999	613	132
2000 (-oct)	347	70

Table 6: Number of articles in free searches about Continuing Medical Education (CME) terms, compared to searches performed using MeSH terms Medical Informatics and Continuing Education

several professional bodies, such as regional medical colleges, scientific societies, and the Health Ministry.

Cryveillance.com estimated that there are more than 2,100 million web pages [Anonymous 00]. Although no specific data are available about health web sites in Spain, Compuware company, using WebCheck utility, has analysed the main companies present in the Internet, and found that 65% of Spanish web sites have important defects in design and access speed. The most common deficiencies were missing attributes, pages under construction, and broken links.

Physicians usually access general search engines in their searches: Alta Vista, Hotbot, Northern Light, Infoseek, Excite, Galaxy, Yahoo, or MSN. They also use specialised servers for Medicine, such as Achoo, Cliniweb, Health AtoZ, Healthfinder, Karolinska Institute, Medical Matrix, Medical World Search, Medsite, and OMNI. Some of the most visited sites are: MedNets (http://www.mednets.com/index.html), Martindale's Health Science Guide (http://www-sci.lib.uci.edu/HSG/HSGuide.html), MedWeb, de la Emory University (http://www.medweb.emory.edu/MedWeb/), MedWeb Plus (http://www.medwebplus.com/), MedMark (http://medmark.org/) and BioMednet (http://www.bmn.com/).

The most frequently used search engines in Spain, as expressed by the Media General Study, are Yahoo (21,6%), Terra (28,9%) and Altavista (17,1%), followed by, Ozú (5,9%), Lycos (5,1%) and Excite (2,2%) [Anonymous 00]. Some frequently visited specialized Spanish web sites are Diario Médico (http://www.diariomedico.com), Recol Network (http://www.recol.es/), MedicinaTV.com (http://www.medicinatv.com), and Saludalia for Physicians (http://www.saludaliamedica.com/).

Virtual Congresses

We started the organization of virtual congresses on Pathology in 1996, (http://www.conganat.org/), and recently, our group was responsible for the organization of the VI World Congress on Biomedical Sciences in Internet – INABIS 2000 (http://www.uclm.es/inabis2000/), see Figure 1. This experience allowed us to evaluate the growing interest that health professionals have in this new type of meetings. In tables 4 and 5 we have summarised the main advantages and disadvantages found in the organization of virtual congresses

6 New information and communication technologies impact in medical literature

We have recently studied the use of terms related to information and communication technologies, using the on-line database [PubMed 00] to perform Medline searches in scientific journals.

In our first approach, we analysed the use of Medline Browser MeSH terms (http://www.ncbi.nlm.nih.gov/entrez/meshbrowser.cgi) such as "Education, Continuing" and "Medical Informatics"). We obtained a total of 1,201 articles, compared with a total of 11,376 articles when non-specific searches about Continuing Medical Education (CME) were performed.

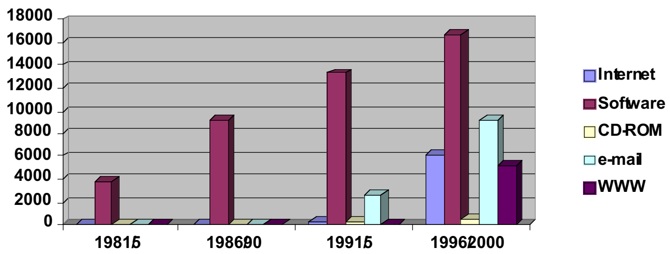

Fig. 2: Frequency of technical terms in scientific articles between 1981 and 2000.

Main Topic	Number of articles		
	1998	1999	2000
Total	91	112	61
New technologies in education	21	24	12
Internet	19	37	22
Medical specialities	18	22	19
Management	11	5	2
Primary care	10	10	5
Software	9	6	2
Medical informatics teaching	8	4	6
Education theory	8	9	1
Not related to informatics	7	6	2
CD-ROM	7	4	2
Evidence-based medicine	4	5	3
Telemedicine	4	2	2
Medical Literature	3	3	3
Decision support	3	2	1
Virtual Reality	2	-	-
Standards	1	2	1
Public health	1	-	1
Law	1	-	-
Emergency	1	1	1
Clinical guidelines	1	2	-
Information systems	1	5	-
Pharmacy	-	4	
Congresses	-	2	
Voice recognition	-	-	1

Table 7: Main topics observed in Medical Education Articles

Table 6 summarizes the last 10 years of evolution in the number of articles in searches using MeSH terms, compared with the non-specific CME term searches.

Term	1981 –1985	1986 –1990	1991 –1995	1996 –2000	Total
Internet	0	0	239	6104	6454
Intranet	10	587	2690	9090	12391
Software	3715	9112	13255	16728	44746
CD-ROM	1	52	295	471	819
e-mail	10	588	2712	9189	12505
Red TCP/IP	0	1	11	20	32
FTP protocol	0	1	20	42	62
On-line & computers	51	53	30	25	285
WWW	0	0	37	5098	5135
Virtual Reality	0	0	93	424	517
Bulletin Board System	0	6	29	27	62

Table 8: Number of Articles in Medline searches on specific terms (1981–October 2000)

Term	1996	1997	1998	1999	2000
Internet	442	689	1284	2222	1467
Software	3076	3683	3775	3824	2370
CD-ROM	106	102	106	93	64
e-mail	1419	1829	2136	2437	1368
Red TCP/IP	5	3	6	4	2
FTP Protocol	9	8	11	10	4
On-line & computers	11	5	5	3	1
WWW	108	218	1102	2230	1440
Virtual Reality	56	102	105	80	81

Table 9: Number of Articles in Medline searches on specific terms (1996-October 2000)

We also thoughtfully analysed those articles related to medical informatics and continuing medical education, excluding nursing, and classified them according to their main topics, as included in Medline abstracts (table 7).

In the second phase, we analysed the frequency of certain terms related to new information and communication technologies during the last 10 years. This is shown in table 8 and figure 2. Table 9 and figure 3 show detailed data about last 5 years.

Notice the use of the term Intranet in scientific articles before Internet technologies were known. Thus, 6 articles mentioned the term intranet from 1972 to 1976, even though it was used with a different meaning, and was applied to any local network. The term Internet appeared for the first time in 1991.

5 New perspectives

In the near future, it will not be easy to distinguish between continuing education resources and health information systems used by doctors in their daily practice of handling clinical history or generating reports. There is an increasing need to integrate screening or checking routines into information systems, which should advise physicians about the appropriate steps to follow. Even more, they could propose specific protocols used by their organization [Shea 96].

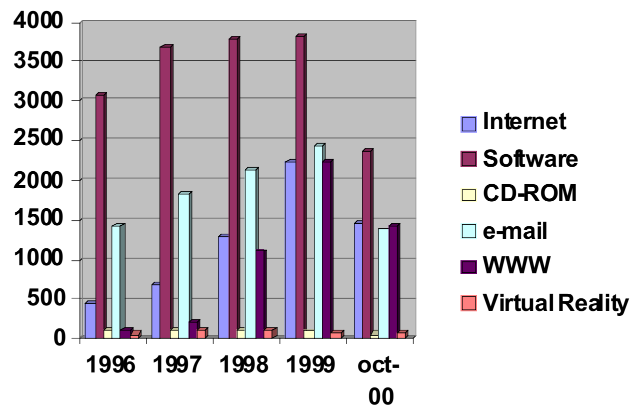

Fig. 3: Frequency of technical terms in scientific articles between 1996 and 2000

Therefore, the presence of integrated medical workstations will be common, an idea developed in the Columbia Presbyterian Medical Center, New York. They had a clinical information system (Web-CIS) with Internet access, access to the servers of the institution working as searching engines on the Internet and an Intranet. Consequently, it is easy to imagine future information systems capable of answering prompts such as "find cases that are similar to this patient's case and show me data about their diagnoses and treatments". The answers will integrate information coming from the Intranet, the public Internet, or from certifying entities.

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Automatic Three-dimensional Reconstruction of Radiological Images for Telediagnosis

Valentín Masero Vargas, Juan Miguel León Rojas, José Moreno del Pozo, Antmael Silva Luengo

In the field of Telemedicine, one of the most successful techniques has been remote diagnosis or Telediagnosis. To improve Telediagnosis, we have constructed an Information System for automatic three-dimensional reconstruction of radiological images. This system has improved the way in which we visualise and examine these radiological images. In this article, we describe the techniques that have been utilised for constructing 3D reconstructions. We also explain several segmentation techniques due to their importance during the 3D reconstruction process.

Keywords: Image Processing, Snakes, 3D Reconstruction, Computer Graphics, Medical Imaging, Telediagnosis, Telemedicine.

1 Introduction

1.1 Project goals

This work started with the project "Development of a 3D Database of Animal Organs (D3DBAO)", supported by the Spanish Intergovernmental Commission for Science and Technology (Comisión Interministerial de Ciencia y Tecnología, CICYT). This project is managed by the Minimally Invasive Surgery Centre (MISC) in collaboration with the Computer Science Department of the University of Extremadura (CSDUEX).

One of the main goals of our project was the automatic construction of both human and animal organs from radiological images. An additional objective was to use our software as a 3D visualisation environment and, later, as biomechanical simulation environment. All together, these will constitute a training system for surgeons based on virtual reality. These additional goals are related to another project called "Telesurgex (Minimally Invasive Surgery by Telecommunication)" supported by the European Community and the Junta de Extremadura (Consejería de Educación, Ciencia y Tecnología). Several researchers of the CSDUEX are collaborating in this project as well.

This article explains a system to automatically construct 3D models from radiological images. This system is still being improved.

While we were constructing this system, it was necessary to improve several techniques for automatically extracting 3D models from CT (Computed Tomography) and MR (Magnetic Resonance) images. Depending on the part of the anatomy needed for 3D reconstruction, it is better use CT or MR images. Thus, we worked with different radiological imaging techniques. For example, to reconstruct soft tissues it is better to use MR images, and to reconstruct a bone structure, it is better to utilise CT images.

2 Background

2.1 Three-dimensional reconstruction and visualisation of medical images

Thirty years ago, few radiologists were interested in three-dimensional imaging. They believed that this technique was not necessary because they could mentally assimilate two-dimensional data and interpret it in a three-dimensional manner.

Since then, three-dimensional imaging has become so advanced that image fidelity is sufficient for worldwide clinical use of three-dimensional imaging in dedicated academic medical centres.

By 1985, clinical application of medical imaging primarily focused on cranio-maxillo-facial surgery and was mainly limited to bone imaging on the basis of CT scans. At that time,

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many radiologists feared being used as a kind of medical photographer merely to provide image data sets to surgeons [Hemmy et al. 94]. However, the complex segmentation process, especially in the case of soft tissue segmentation, clearly required radiologic skills, both to recognise and isolate the relevant structures in the two-dimensional cross-sectional scans. Later, three-dimensional imaging was introduced in other types of surgery with the help of other imaging modalities such as surface and volume rendering.

During the last decade, three-dimensional imaging has attracted more and more devotees mainly because of its realism and ability to interact with the 3D images. It allows visualisation from different views and several graphical transformations over the visualised three-dimensional objects. 3D visualisation has also been used for automatic detection of several diseases, such as cancer tumours, showing them in a different colour [Wyatt et al. 98]. In radiology, recent systems for distance diagnosis or telediagnosis have been developed, e.g. Hideyuki's system [Hideyuki et al. 98].

But, to be able to apply these three-dimensional imaging techniques, we must apply an efficient segmentation process beforehand.

2.2. The most widely used techniques for segmentation of medical images

Segmentation is the process of recognising objects within an image. As stated above, it is an indispensable step in most of the processes that are applied to medical imaging. For example, for measuring the volume of anatomical structures, for making three-dimensional reconstructions of medical images, or for making a good 3D rendering, it is important to develop an optimal segmentation.

It is important to emphasise that no general segmentation method exists which is able to isolate any object in any kind of image. That is, depending on the problem to solve and the given image, several segmentation methods are suitable. And, in most cases, no one method gives perfect results, so we need to adapt these techniques to our needs by using hybrid techniques.

The most widely used medical imaging segmentation techniques can be categorised into two classes:

1 feature thresholding methods,
2 region-based methods.

Among the region oriented methods, there are two subcategories: the region growing method and the texture analysis method. We do not mention the technique of cluster analysis which is basically a feature extracting technique and a multidimensional extension of the concept of thresholding.

Segmentation by thresholding has the advantage of being computationally simple and fast. It works well on objects with uniform intensity values which differ significantly from all other objects and the background. The thresholding fails, however, if the objects do not differ in intensity values but in some other property (e.g. texture).

Region-based methods assume the objects in the image to be a closed region. With this model of an object, two general approaches are possible: finding the border of the region (i.e. the edge oriented methods), or finding the interior of the region (i.e. the region based methods).

We distinguish two techniques to find the interior of a region. One technique is called texture analysis, whereby each pixel with its neighbourhood is classified individually as belonging to the region or not. The other technique is called region growing, an iterative method, whereby the image is processed several times. Each step of the iteration improves the result of the previous step. Problems discussed in this field are finding the seed points, the way of growth, the break of growth, and the split and merge of regions [Gonzalez/Woods 92].

Segmentation by edge detection methods is based on identifying significant intensity changes as edges of the objects in the image. The edge detection can be divided into the following steps. First, the image is preprocessed or conditioned, concentrating on brightness and contrast. Second, the first or second derivation of the signal is calculated. Finally, depending on the used derivation, the local maxima or the zero crossings are detected and marked as edge pixels [Gonzalez/Woods 92].

3 The Information System

The information system [Masero et al. 00] for automatic 3D reconstruction of radiological images is mainly formed by: a radiological device (RD), a workstation connected to the RD, a data server, an ATM telecommunications network, a Personal Computer (PC) connected to the system via Internet, and a computer program [Masero et al. 00]. In this article, the data server and the telecommunications system are called "Picture Archiving and Transmission System". The computer program is being finalised by the CSDUEX in collaboration with the MISC team.

The workstation allows us to provisionally store the radiological images and, optionally, process them for making the three-dimensional models. The user can make new 3D reconstructions remotely and visualise them on the screen of a remote PC connected to the system via Internet. From this PC several graphical operations can be applied to the 3D model, such as translations, rotations, scaling and, generally, all kinds of geometric transformations based on these operations. Therefore, the user can obtain new 3D images and study them better by using the options offered.

4 Methodology for 3D Reconstruction

Figure 1 shows the process for creating three-dimensional reconstructions. In this process, we have used a methodology based on image processing and computer graphics techniques.

Several computer graphics techniques, such as surface rendering and volume rendering, have been used.

Initially, all the techniques that appeared in the section, "The most widely used techniques for segmentation of medical images", were tested on several datasets, but no acceptable results were obtained. So, we realised that it is not possible to achieve good segmentation results utilising the same segmentation techniques for every kind of anatomical structure. Therefore, we applied different segmentation techniques, depending on the part of the body for which we wanted to make a 3D reconstruction. Finally, among all the applied techniques,

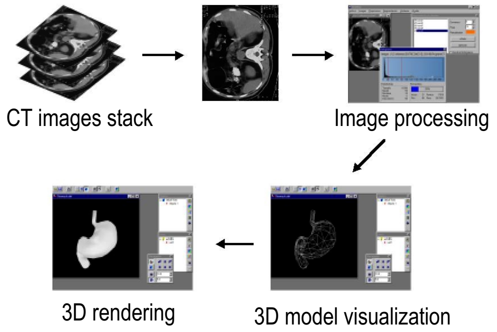

Fig. 1: 3D reconstruction process.

Snakes [Kass et al. 87][Honea et al. 97][Blake/Isard 98] was the method with the best results.

4.1. Snakes

Snakes were first described by Kass, Witkin and Terzopolous [Kass et al. 87]. A snake is a sequentially connected set of points, each located at one pixel in the image [Honea et al. 97]. The method of snakes is an energy minimization technique that uses information both on the object's shape and its image properties to determine the segmentation of the object. The snake has an energy, called external energy, that arises from the image characteristics at each snake's point location. The snake also has an internal energy, based on its shape.

This method requires that the snake be initialised to a path near the true object boundary. At each snake point, a set of nearby pixels is chosen as a neighbourhood in which the current snake point may move. During optimization, the lowest energy path is sought, and each snake point is moved, if necessary, to the path that has the minimum energy path. The process is repeated until no further movement of the snake is needed.

As result of applying an image operator to each snake point, we obtain the external energy at that pixel location. In this way we assign lowest energy to points that show good image qualities, and higher energy to other points. The good qualities are defined as those that usually happen at the border of the object we are examining (e.g. high intensity pixels). We can define the external energy as:

$$E_{ext} = -\left|\nabla I(x, y)\right|^2$$

The internal energy gives a smoothing constraint on the shape of the snake. This energy is formed by two terms. The first one causes the snake to behave as an elastic band that resists stretching. This first part can be written as:

$$E_{int1} = \sum_{i=1}^{n} \left|v_{i+1} - v_i\right|^2$$

n being the length of the vector and v a point of the vector where $v_i=(x_i,y_i)$.

The second part makes the snake behave as a flexible rod. It can be defined as:

$$E_{int2} = \sum_{i=1}^{n} \left|v_{i+1} - 2v_i + v_{i-1}\right|^2$$

All these terms are weighted to contribute in the appropriate influence to the whole snake energy.

$$E_{snake} = a \cdot E_{ext} + w_1 \cdot E_{int1} + w_2 \cdot E_{int2}$$

4.2. The whole 3D reconstruction process

In the system that has been built, the following process is needed to transform radiological images into three-dimensional models.

0. Setting environmental parameters, i.e. parameters associated with the radiological imaging device.
1. Acquisition of the radiological images. Always under conditions set on step 0.
2. Images preprocessing. Processes of brightness, contrast and histogram in order to eliminate noise and undesired information, that is, in order to have acceptable initial conditions.
3. Bidimensional segmentation: depending on the anatomical structure to delimit, we use a different segmentation technique or a hybrid one. For example, region growing or Snakes.
4. To select the regions obtained in the previous step and to connect them to form a three-dimensional model.
5. Three-dimensional models are made without additional operator interaction by propagating the 2D results to adjacent slices.
6. To export to appropriated graphical formats (ASC, 3DS and VRML) in order to later visualise and manage the 3D model in the developed visualisation software [Masero et al. 00]. The computer graphics techniques used have been Surface and Volume Rendering Techniques.

The software for visualising the 3D models has been developed using the visual programming environment Delphi 5® and the graphic library Open-GL®. It has been made for Windows 98® and Windows NT®. However, another version is being developed for Linux using C++.

5 Conclusions

We have designed an information system for obtaining three-dimensional reconstructions, remotely, from radiological images. This information system is based on a software which utilises several classic image processing methods [Gonzalez/Woods 92] and others more recent such as snakes [Kass et al. 87]. It also utilises a standard telecommunications network. To carry this out, a computer program has been developed. With this software, the physician can better study the zone of interest by studying it from several views. However, the main contribution of this work has been the improvement of the segmentation of radiological images by using snakes; and, therefore, the improvement of the 3D visualisation of the anatomical structures shown in the radiological images.

Our system, in addition to allowing the visualisation of stored images like the system described by Hideyuki [Hideyuki et al. 98], also permits interaction with previously stored 3D models. It also allows the creation of another 3D reconstruction from the images stored in the workstation or picture archiving system.

This software gives greater independence to physicians working in areas with limited resources. It allows the visualisation of 3D images of the anatomical structure of interest from any rural area. It also allows physicians who do not have a very powerful computer to control the remote three-dimensional images without having a workstation, which would be too expensive.

In the future, we would like to improve the visualisation of 3D imaging in order to improve diagnosis. We could also improve image segmentation that will allow us to see cancer polyps and other diseases more difficult to diagnose nowadays.

Acknowledgements

This work would not have been possible without the support of the Spanish Intergovernmental Commission for Science and Technology (Comisión Interministerial de Ciencia y Tecnología, CICYT) for the project "Development of a 3D Database of animal organs (D3DBAO)". We also wish to thank the European Community and the Junta de Extremadura (Consejería de Educación, Ciencia y Tecnología) for the "Telesurgex (Minimally Invasive Surgery by Telecommunication)" project support. These are two projects of the Minimally Invasive Surgery Centre (MISC) on which the Computer Science Department of the University of Extremadura (CSDUEX) is collaborating.

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Artificial Intelligence in Medicine. Past and New Applications

José María Barreiro, José Crespo, Víctor Maojo

This article offers a general overview of the history of research in the field of Artificial Intelligence in Medicine. The first experiences were based on the use of cognitive models of medical reasoning, and gave rise to expert systems. Among these models that tried to emulate the language of physicians MYCIN was the best example. A second generation of systems were designed to fit better into the clinical routine environment. Finally, some examples of current research developed by the group are given such as: (1) a mobile system for emergency health care; (2) a system for accessing MEDLINE in Spanish, based on a medical vocabulary server; (3) a virtual system for training in trauma surgery. In these systems we use hybrid systems that combine Artificial Intelligence tools with Internet-based information management.

Keywords: Medical Informatics, Artificial Intelligence, Expert Systems, Internet, Databases, Emergencies, Virtual Surgery.

Introduction

Artificial Intelligence is a branch of Computer Science that begun at a meeting held at Dartmouth College in the United States in 1956. The original goal was to conceive intelligent machines that could replace human beings or perform tasks that could be considered similar to those of human beings. While initially the goal of making intelligent machines was an abstract one, it soon became clear that there was a possibility of creating intelligent systems for practical real-world applications.

After completing research into the cognitive issues of medical reasoning and computer-assisted diagnostic systems, researchers from universities like Stanford, MIT, Rutgers and Pittsburgh started to work in the 70s on what are known as expert systems, medical examples which include MYCIN, PIP, CASNET or INTERNIST.

Some years earlier, during the 60s, several groups of physicians at hospitals in Boston, Salt Lake City, in the USA, and Geneva (Switzerland) had proposed the use of early commercial mainframes, like UNIVAC and its successors, in clinical applications. This led, for example, to the early computer-assisted diagnostic systems and the first computerised clinical records. The above clinical applications were implemented at hospital computer centres by programmers, systems analysts and clinical physicians interested in their use. The goal was to create applications that could perform the calculations which occupied so much of physicians' time.

The following list provide an outline of the main methods used at that time in computer-assisted decision-making:

1. Decision analysis
2. Mathematical models of physiological processes
3. Databases
4. Clinical algorithms
5. Pattern-matching methods

Some researchers had been working on the study of reasoning processes required for issues of medical practice, such as, for example, clinical diagnostics. By the end of the 60s, they had found that diagnostics is an iterative, inference-based process of determining the type and circumstances of a disease by examination. Clinical reasoning was no longer viewed as an art, the result of a clinical eye or the intuition of the best specialists, and came to be considered a formal question that could be modelled. Its main components were the following: produce a first hand identification of the cause of the symptoms and signs of the patient, gather important information, select the best diagnostic tests and recommend treatment. This process is governed primarily by the hypothetical-deductive method, as a

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series of hypotheses are stated and refined by means of methods of deduction.

The research of Simon and Chase at Carnegie Mellon and that of other researchers, like Tversky, Kahnemann, Pauker or Anderson, laid the foundations that were to unveil the fundamentals of the cognitive processes of general and medical reasoning and for the use of this knowledge to build systems that reasoned similarly to physicians. They noticed that physicians used a series of rules of thumb or heuristics to reduce the search space required to achieve their goal (for example, diagnosis). Physicians estimated the probabilities of diseases by comparing diseases rather than using data from formal probabilistic statistics or decision analysis. The main heuristics were:

1. Heuristics of representativeness: the probability of a finding is estimated by comparison with population statistics.
2. Heuristics of availability: the probability of an event is estimated according to how easily it can be remembered.
3. Heuristics of anchoring and adjustment: physicians make an initial estimate, which is then adjusted depending on the characteristics of the patient under examination until they arrive at a final assessment.

Other processes involved would be, for example, generalisations and abstractions of facts discovered during the reasoning process, recognition of patterns to quickly state diagnostic hypotheses or the application of joint actions prepared beforehand.

These early computer-assisted diagnostic systems did not work well because physicians found it difficult to deal with probabilistic concepts. They discovered that the systems had to speak the same language as physicians and be able to explain their reasoning rather than act like black boxes. The earlier success of expert systems, like DENDRAL, in other areas proved that it was possible to capture the knowledge and reasoning methods of the best medical specialists.

MYCIN is the most widely known early medical expert system. It was designed for the treatment of infectious diseases (septicaemia and meningitis). It was an academic, rather than a clinical success, as it was not routinely used outside Stanford, where Shortliffe created it. Indeed, its creator says that it was used in only one hospital in Japan, because a head of department forced his team to do so. MYCIN was an IF… THEN… rule-based expert system, containing about 450 rules.

MYCIN also introduced a new method for handling uncertainty, which was created informally within the system. It consisted in the use of certainty factors associated with knowledge, which were later proven to be equivalent to Bayes' models.

MYCIN had a fairly novel interface for the time, although physicians did not find it easy to use. An example of an interactive consultation with MYCIN is given below:

```
1. Patient's name: (first-last
   ** FRED BRAUN
2. Sex:       (Questions 1-3 request
   ** M       background patient data.)
3. Age:
   ** 55
4. Are there any cultures for Fred Braun
   which may be related to the present
   illness, and from which organisms have
   been grown successfully in the
   microbiology laboratory?
   ** Y ----CULTURE-1-----
5. From what site was the specimen for
   CULTURE-1 taken?
   **BLOD =BLOOD (System corrects typing
   error.)
6. Please give the date and time when
   CULTURE-1 was obtained. (mo/da/yr time)
   ** JUN 20,1977 The first organism isolated
   from the blood culture of 20-JUN-77
   (CULTURE-1) will be referred to as:
   ----ORGANISM-1-----
7. Enter the laboratory-reported identity of
   ORGANISM-1:
   ** UNKNOWN (Typically identity is not yet
   known.)
8. The stain (gram or Ziedl-Neelsen acid-
   fast) of ORGANISM-1:
   ** NEG (Preliminary lab results give some
   clues.)
9. Is ORGANISM-1 rod or coccus (etc.):
   ** ROD
10. What is the form of the individual
    organisms (e.g. Iancet- shaped for
    cocci, fusifomm for rods, etc.)?
    ** FUSIFORM
…
```

The knowledge base could be modified so that engineers could introduce new knowledge, an idea that, due to scientific discovery, was an absolute must in Medicine. A module was also created to justify system reasoning, which showed the list of rules used by MYCIN.

The program, called inference engine, that handled the knowledge was successfully marketed and used to build expert systems in other areas. Paradoxically, the MYCIN model and spin-off tools were used to develop expert systems in areas far from Medicine, such as defence, banking or industry.

MYCIN was created as a question of academic research rather than in response to a real clinical problem. Therefore, it had the following problems:

(1) A consultation took longer than 15 minutes, time that a physician normally could not spend on just one consultation.
(2) MYCIN was more confident about its diagnoses than specialists, but its errors led to mistrust on the part of users.
(3) The explanations given by the system about its findings were simple and were only justified by the list of rules that had been fired.
(4) The interface was neither graphic nor easy to use.
(5) Physicians had to use MYCIN outside the clinical environment with the help of computer scientists.
(6) The knowledge contained in the system was heuristic-based but contained almost no deep information, that is, about the causes and processes underlying the disease.

To be able to replace physicians, programs were generally designed as absolute oracles. Even though the expert systems contained specialist knowledge in a field, they failed to model how people reason, including the use of common sense.

Medical Informatics emerged as a separate discipline in the 80s, and the appearance of personal computers meant that physicians had access to applications for clinical, academic, research and management use. This led to the gradual emergence of a new paradigm: physicians should be able to access all the medical information and knowledge they needed from their computers. Therefore, artificial intelligence techniques combined with software engineering techniques create more efficient systems integrated into the medical environment.

The next generation of expert systems tried to capture knowledge in a way similar to the one physicians use in their reasoning strategies. MYCIN or INTERNIST, based on heuristics or shallow knowledge, could not capture the complexity of the knowledge of medical specialists. These new systems incorporated deep knowledge on the causes of a particular disease, including new reasoning capabilities, qualitative, causal, temporal, semi-quantitative models, etc.

Systems like ABEL, for analysing acid-base disorders, or ROUNDSMAN, with a library of knowledge composed of many articles, search for those most closely related to the patient in question, or KARDIO, which used an automatic learning system to elicit rules from the system of large databases, marked a change of approach from the early expert systems.

These systems were not designed to answer questions raised by an expert in a given domain. Nor were they intended to model the diagnostic process. They were primarily systems that gave specific advice or criticised certain medical decisions. New temporal and probabilistic models were also introduced that provided greater capabilities. In addition, graphical user interfaces were created, which made systems more user friendly. Issues like logical knowledge verification and more extensive validations were considered in more detail to assure their clinical impact outside the laboratory in which they were created.

They were only partially successful as well because they had similar drawbacks like the 1st generation, as well as one in particular: physicians generally had neither the time nor the patience to enter into a prolonged dialogue with the computer, into which they also had to manually enter patient information.

90s

Twenty years after the first expert systems appeared, they were still not clinically successful in routine medical practice. Only systems like INTERNIST (now called Quick Medical Reference or QMR), for example, had been commercialised and used in a host of health system environments. As a result, new artificial intelligence-based models emerged using different concepts founded on new symbolic methods and, also, on connectionist models. Of these, artificial neural networks and case-based reasoning were prominent.

As of the 90s, new medical informatics systems based on the use of artificial neural networks appeared. They have been integrated into commercial systems and used, for example, in radiological diagnosis (for example, early cancer detection), in the classification of electrocardiograms and electroencephalograms, or in ICU systems.

Artificial neural networks can also be used as a method of data mining for eliciting knowledge from data warehouses or large databases (for example, complex clinical records).

Artificial neural networks were not as successful as originally thought, due to several factors. Problems include the number of cases required to train and validate the system, the epidemiological mistakes made in selecting these cases, the black box concept of these systems and their own errors. Thus they are trusted by clinical physicians (although they were often more correct than the specialists with whom they were compared).

The other model, case-based reasoning, considers the physician's diagnose of a patient in comparison with earlier cases. Thus, when faced with a new patient, the system searches for a similar patient in a case library. It makes a comparison, establishes the differences in order to reach a diagnosis and recommends a series of actions. This information is then stored in the library and the system operates accordingly.

The problem with this technique is that very similar cases are seldom found in Medicine. Moreover, the fundamental cognitive question is whether or not physicians actually use a combination of several reasoning strategies, which can be related to several of the techniques discussed above (heuristic search, pattern recognition, qualitative and causal reasoning, case-based reasoning). Therefore, one technique alone cannot capture the complexity of medical reasoning.

A combination of all these techniques would be an ideal formula for building an artificial intelligence system in medicine. Examples of these have already appeared, like PERFEX, a computer-aided SPECT image diagnostic system that combines a rule-based symbolic model with an artificial neural network connectionist model.

Present and future research

A host of clinically unsuccessful programs based on artificial intelligence techniques have been built over the last 25 years. Indeed, many were built merely as research experiments, and were not designed as solidly as, for example, the clinical trials run on new drugs. But some systems have been used clinically and commercially. Not only are these systems not public, their use has not been publicised (for example, some US medical insurance companies have expert systems for evaluating the quality and costs of health care).

In recent years, increasingly small systems have been designed for integration into hospital information systems (called HIS), like what are known as Medical Logical Modules, based on ARDEN Syntax. This syntax, similar to PASCAL, can be used to specify small computer-aided decision-making systems that can be easily integrated into more complex systems.

The rise of what is known as evidence-based medicine has promoted the development of programs that are based on negotiated knowledge, a combination of scientific literature and the opinion of expert panels, expressed as clinical practice guidelines and protocols. A host of software tools has been built with languages suitable for specifying protocols, which interact directly with clinical records to extract the data required to support decision-making. One of the models most commonly used for representation is the flow diagram, with state, action and

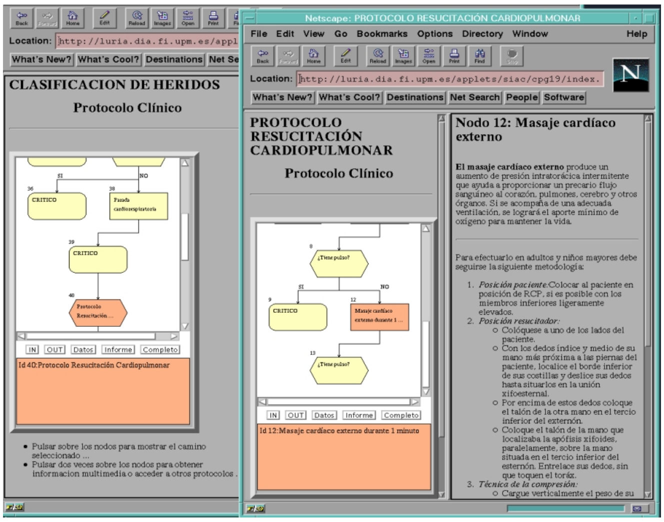

Figure 1: Emergency protocol management (version 1 in JAVA)

decision nodes, as illustrated in Figure 1, showing a system developed by our laboratory for managing emergency protocols.

Using the standard interfaces of common navigators and systems based on the use of CORBA or JAVA, new technologies can be used across the World Wide Web to develop small applications or components. These components are designed for very specific functions, which interchange messages and operate within a clinical workstation. Thus, computer system developers can easily implement small applications that can be reused in other domains or interchanged with other groups.

One essential requirement for the interchange of information is a common vocabulary which can be understood by all applications. This is particularly difficult in Medicine, where one concept can have different names in a specific same language. Therefore, an idea emerged, again in the USA, of a unified vocabulary which integrated all the existing medical vocabularies and could act as the link between different information systems from a semantic viewpoint. This vocabulary, called Unified Medical Language System, UMLS, is particularly useful for vocabulary servers.

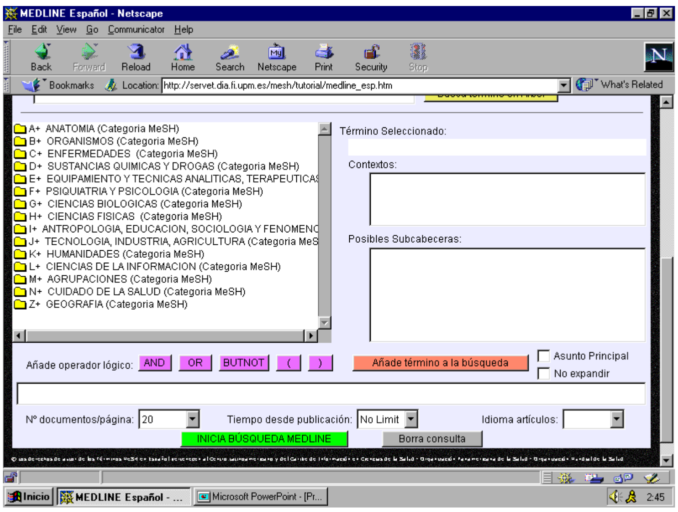

Figure 2: Access to MEDLINE in Spanish.

Our group has developed a vocabulary server, based on UMLS and other well defined medical vocabularies, designed to exchange information between heterogeneous systems. This server can be used over the Internet to identify terms or codes from different remote medical systems by means of Artificial Intelligence techniques. It has also been used to develop a system implemented in JAVA to access MEDLINE using Spanish terms, which is shown in Figure 2.

The nucleus of medical practice is the patient. Similarly, the nucleus of medical informatics is the computerised clinical record. This document contains the data required by physicians to assess, diagnose and treat a patient. Physicians should have systems related to clinical records as aids for managing the data, information and knowledge required for health care. Systems are needed now and in the near future to help to search and select the necessary information within the World Wide Web.

In the USA, the NII (National Information Infrastructure) initiative and the forthcoming generations of Internet, with Gigabits/sec transmission speeds, will soon provide real-time access to information contained in graphics, video, sound and the routine creation of telemedicine applications. This will make it possible to transmit all sorts of medical images, virtual reality applications, videoconferences, etc., which will radically change the face of medical practice.

Our group is working on a joint project, with the Ministry of Defence's General Health Inspection Unit, concerning the transmission of images for use in distance surgery planning and in virtual head injury surgery systems. The goal of this project is to help surgeons perform real operations and provide a virtual education system for training surgeons. Even though, fortunately, Spanish military physicians are unlikely to be involved in many wars, these systems can help simulate real situations and hence improve the training of these surgeons. Since it takes 10 to 15 years to train an expert surgeon, the use of these intelligent teaching systems can reduce this span of time and improve the response for situations that are unusual in peacetime. A screen of the prototype is shown in Figure 3.

With this and other similar projects, patients already have access to this new information, which heralds a genuine revolution in medicine. No longer merely a subject for study, patients will become agents that access, exchange and generate information. Therefore, systems have to be built not only to assist health workers but also patients. These include intelligent systems, like agents that navigate, search and filter important information over the Internet. They are called guardian angels, which are systems integrated into each patient's clinical records that know their background and preferences and can rule out any decision that could otherwise compromise their quality of life.

In the United States, new genetic clinical records are being created, in which diverse genetic information can be efficiently added. Therefore, the results of technologies like biochips are likely to have an immediate impact on clinical practice even in

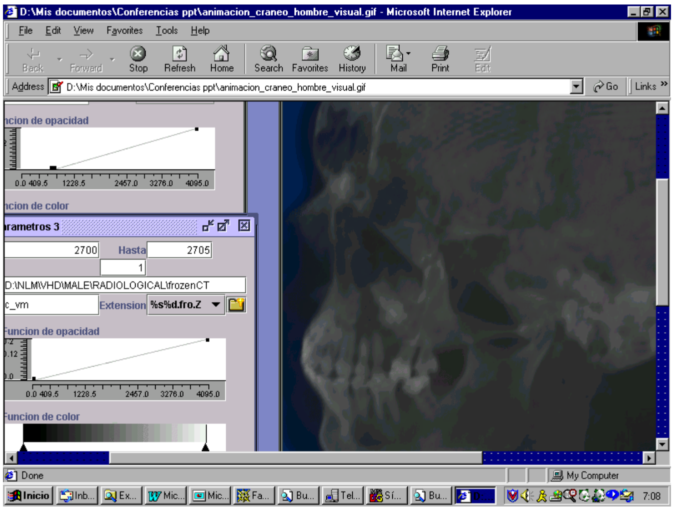

Figure 3: 3D navigation system for head injuries

primary care. Thus, it will also be possible to analyse risk factors or regional prevention campaigns. They will probably be commercialised by 2002.

The latest generation of mobile telephony technology, like WAP and, especially, UMTS and their immediate successors, as well as its integration into agenda-sized computers (personal digital assistants or PDAs) with improved screens and architectures, will give health care workers and patients multiple, mobile, universal and rapid access to remote computer-aided decision-making systems. This includes access, for example, to systems integrated with clinical records or radiological images from any part of the world with no access to cable networks.

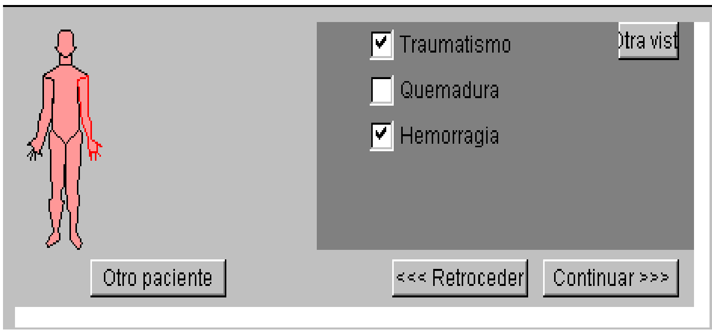

Figure 4: Emergency aid prototype system for PDAs

The European Commission is supporting this future technology by carrying out research projects that could be concluded within the 2002/04 period and then marketed.

Figure 4 is an example f a screen of a system implemented by our group jointly with physicians from the EMAT, at the Gómez-Ulla military hospital of Madrid and the Ministry of Defence's General Health Inspection Unit. It is designed to handle victims in two sorts of emergency situations: military emergencies (victims of combat in wars) or civil emergencies (common medical emergencies or disaster situations). This system is designed to be for use in portable computers and future PDAs, which are connected to computers based at reference hospitals, and can be adapted for use within UMTS networks.

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A Case Based Reasoning Decision Support System for use in Medicine

Joël Colloc and Laïd Bouzidi

Our DSS integrates different kinds of decision models and uses them to deal with the successive clinical decision steps: diagnosis, prognosis and therapy in the complex medical field. The decision process includes patient data, experts' knowledge, statistical and epidemiological data and previously stored experience. The Case Based Reasoning (CBR) approach is used to store and retrieve the clinical cases. This approach is viable in other complex fields that require a high level of expertise such as engineering design, computer design.

Keywords: Decision Support System, Case Based Reasoning, Multi-Agent system, Machine Learning, Clinical Decision, Knowledge Base, Epidemiology

1 Introduction: the clinical decision context

A decision problem can be defined as a choice between several options in order to achieve a goal as efficiently as possible. Most of the time, the physician's ability is beyond the computer's capability and thus, trying to supply a decision support system to aid him or her is worthless. The best example is diagnosis. However, medical activity could be defined as a *decision chain* (more exactly a decision network) that involves the following steps: the diagnosis, the prognosis, the therapeutic and the treatment follow-up.

Some of these steps become more and more complex and an aid tool will be useful, especially during the prognosis and therapy stages.

Artificial intelligence scientists were very interested in the cognitive nature of the physician diagnosis activity. So, many applications have been developed in this domain. We have to admit that most of them are unused, because they do not bring any actual enhancement. Paradoxically, many physicians are interested in information systems and some of them have developed small or sometimes more sophisticated Decision Support Systems (DSS).

1.1 Medicine complexity

Medicine is a science based on the human organism observation. Diseases are dynamic processes, but clinical syndromes are only pathologic snapshots, corresponding to evolution stages. Some diseases progress by steps in a linear way.

For example multiple sclerosis displays successive evolution steps. Others progress in a cyclic manner such as the duodenal ulcer or the herpes infection. Therefore, time is a major factor when describing pathologies [Summons et al. 98].

The effect of an inappropriate therapy or another underlying disease can interfere and give unusual clinical aspects.

1.2 Integrating quantitative and qualitative decision methods

Usually, decision support models in health care can be grouped into two main categories: quantitative and qualitative models.

Quantitative models are based on statistical methods and try to assess the disease occurrence probability for a given patient belonging to a population, when he or she shows some clinical signs or symptoms.

Qualitative models rely on expert knowledge and symbolic reasoning methods, which handle Boolean logic rules. When using qualitative methods one needs to cope with issues such as the experts' knowledge acquisition bottleneck, heuristic detection and the knowledge base implementation.

The models can also be grouped according to the learning method employed. Two types of learning are used: *supervised learning* in which, for each case of a training set, the correct solution is provided to the system by one or several experts, and *unsupervised learning* where the system must automatically determine which feature subset, or cluster of a set of features is relevant to characterize a given identified situation (i.e., a dis-

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	Supervised learning	Unsupervised learning
Quantitative models	Neural networks Fuzzy sets Bayesian models	Neural networks Genetic algorithms Case-based reasoning
Qualitative models	Semantic models Object and frames Logic rules Decision trees	Case-based reasoning

Table 1: A decision model classification

ease) [Van Bemmel et al. 97]. Table 1 displays a Caroll diagram that represents a classification of the main decision models.

1.3 The Case Based Reasoning Model

The Case Based Reasoning (CBR) approach can be described as a third intermediate model, because it makes use of concepts coming from both qualitative and quantitative methods. On one hand, the quantitative methods provide the CBR approach with tools to automatically select the relevant features and to achieve the previously solved case indexing. On the other hand, the qualitative methods offer means to represent the experience gained in solving previous problems. Knowledge models have indeed the necessary semantic capabilities and thus are well suited to describe the case environment and circumstances. We briefly present a CBR model to store the clinical experience in the third section of this paper.

2 The medical decision process features

2.1 Components and stages of a standard decision process

According to Simon [Simon 77], the decision process is composed of four successive stages: 1. Intelligence: collecting static and dynamic data; 2. Design: designing scenarios; 3. Choice: choosing the more relevant scenario; 4. Implementation: evaluating the issues and if necessary providing a strategy update. Data collection is mainly supported by data bases and mathematical or statistical model bases [Pomerol et al. 93]. Dynamic information is provided by the decision-makers and is stored in knowledge bases. The decision bases are designed and implemented with the help of subsystem 1 and subsystem 2 (Figure 1). The chosen decision evaluation is based on the consecutive action impact analysis.

The DSS is composed of four subsystems:

- *Subsystem 1* (intelligence) is used to collect static data and is mainly based on databases, mathematical and statistical models and their corresponding management systems. Therefore, qualitative and quantitative data are extracted and then used by treatments according to the decision-maker. Relevant information is provided to the decision-maker in various formats: feature tables, scenarios, forecasting simulations, dashboards etc. Collectively this information is called *result Info* in Figure 1.
- *Subsystem 2* (design) collects dynamic information based on experienced decision-maker's knowledge and know-how. The domain knowledge is structured into chunks that are distributed according to a competence hierarchy or lattice. Subsystem execution is controlled by an inference engine (IE) but is supervised by the decision-maker. The result is an expert knowledge base (KB).
- *Subsystem 3* (choice) is concerned with designing and generating the decision base. It helps the decision-maker build a set of relevant decisions. This operation is based on information provided by a case base, which provides knowledge about similar previous experiences, and subsystems 1 and 2. The case base memorises the context and the previous reasoning processes used to solve (or fail to solve) previous problems. The output of Subsystem 3 is a decision matrix called the *decision base* in Figure 1.
- *Subsystem 4* (implementation) is used to choose the more appropriate decision between those selected during the

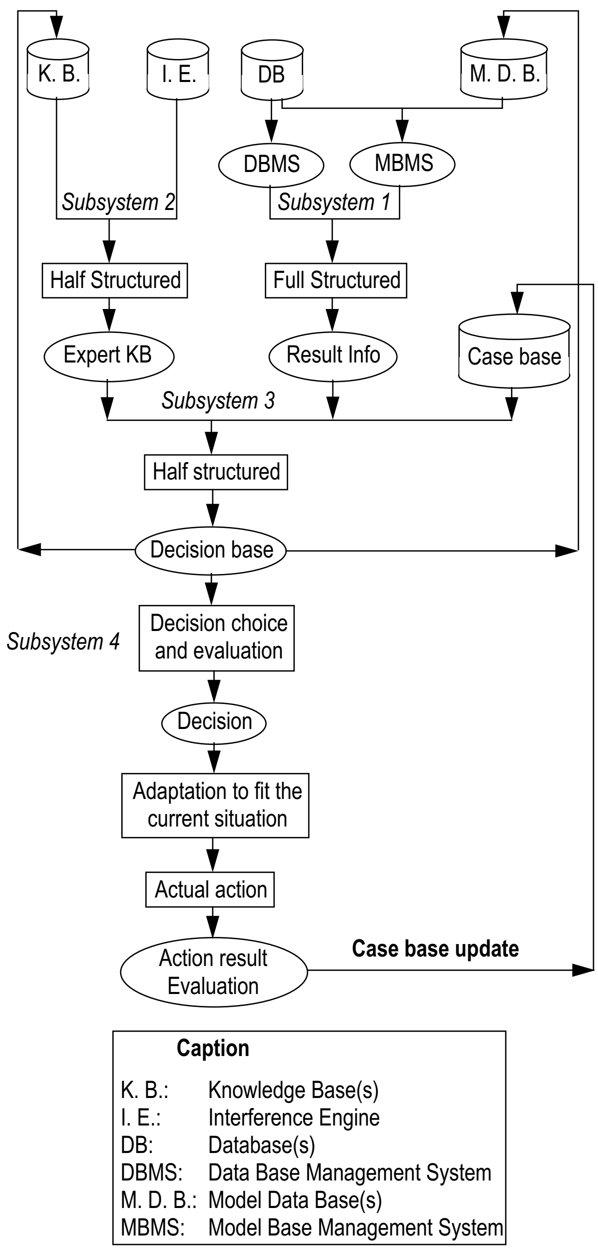


Fig. 1: The decision support system architecture

previous stage and to evaluate the impact of the applied decision. During a first step, the decision-maker browses and analyses the weight of each potential decision. Next, he has to list the relevant actions to achieve the selected decision (*strategic level*, *operational level* and *control level* actions).

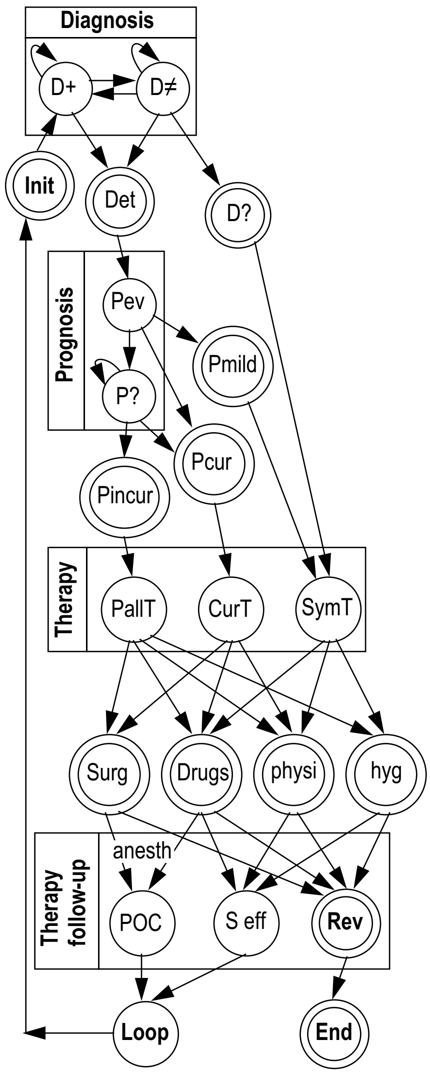
Finally the decision-maker will be invited to evaluate the results and the impact of the selected decision in terms of facts, events, action consequences and to enrich the case base with the gained experience. This operation is depicted on Figure 1 by the *case base update* labelled arrow. Thus subsystem 4 closes the loop of the system's knowledge acquisition process.

2.2 A clinical decision model

The physician must predict the disease evolution, and know the previous therapies and their results in order to choose an appropriate treatment to improve the patient's health. One important aspect of a physician's knowledge is their related clinical experiences with similar cases (the essence of the case based reasoning approach).

We provide a definition and a representation for diagnosis, prognosis, therapy and therapeutic follow up.

The diagnosis is based on medical and surgical semiology: the clinical signs and events, which guide the physician to identify the disease. Semiology is a science that studies the clinical sign's nature, and how their combinations and evolutions define clinical pictures. Experienced physicians often memorized these decision schemes, made them unconscious and, thus, difficult to formalize. During the *positive diagnosis step (D+)*, the physician considers current complaints, the medical history, and the genetic and social background of the patient. Through examination of the patient, the physician searches for the clinical signs that we classify into three different types: pathognomonic signs, evocative sign and accessory signs. During the positive diagnosis step, the physician is making hypotheses relevant to the patient's clinical state. During the *differential diagnosis step (D≠)*, the physician is searching for the existence or the lack of specific signs in order to eliminate those which are not relevant from the previously elaborated hypotheses. The *aetiological diagnosis (Det)* is the correct result of the diagnosis process. It explains the disease appearance, manifestations and evolution causes. Sometimes, the physician is not able to find the disease aetiology *(D?)*, because the clinical picture is very unusual and he must act very quickly to avoid the patient's death. So, he must cure the main syndromes to get time to do further investigations. The diagnosis information will be useful to the prognosis as well.



Caption	
D+	Positive diagnosis
D≠	Differential diagnosis
Det	Etiological diagnosis
D?	Uncertain diagnosis
Pev	Prognosis evaluation
Pmild	Mild illness
P?	Reserved prognosis
Pcur	Curable disease
Pincur	Incurable disease
PallT	Palliativ therapy
CurT	Curative treatment
SymT	Symtomatic treatment
Surg	Surgery
Drugs	Drug prescription
Physi	Physiotherapy prescription
hyg	Hygiene advise
POC	Postoperative complications
SEff	Side effects
Rev	Recovery
○	Intermediate state
◎	Final state
→	State transition

Fig. 2: The clinical decision system cycle

The prognosis stage is often ignored in medical DSS. It is nevertheless essential because it allows the system to fix the therapeutic goal. The prognosis is a difficult task in the course of which the physician tries to predict the patients clinical state evolution and the probable outcome (healing, stabilizing, and death). The necessary knowledge and data derives from many sources: the aetiological diagnosis, the patient general clinical state (the genetic and social background, the psychological factors, the physical characteristics, the past medical history), the stage of the disease; the qualitative knowledge concerning well known clinical scenarios representing likely evolutions, as well as the quantitative knowledge provided by epidemiological studies based on statistical data. Perhaps, the most relevant knowledge comes from observation of some similar cases, which leads the physician to think that the evolution of the present disease will be similar. A CBR approach is used to memorize disease clinical evolutions.

The therapy step: The physician must know the available therapies, the indications for administering drugs, pharmacology data, contraindications, drug interactions, drug toxicity and adverse effects. The physician has previous prescription experience that allows him to predict the effect of a therapy strategy in similar cases. A therapy is prescribed to achieve a goal. A curative treatment (CurT) aims at totally curing the patient or consolidating his clinical state (to stop the disease evolution). For example: an antibiotic prescription to cure tonsillitis. A preventive treatment (PrvT) is prescribed to prevent a serious disease occurring, as in the case of vaccination or antibiotic prescription before a septic surgical operation. A Symptomatic treatment (SymT) cures disagreeable effects and functional manifestations of a disease, for example a headache. A Palliative treatment (PallT) is prescribed when the prognosis is hopeless and the aim is no longer to cure but to procure more comfort for the patient.

During the therapy follow-up step, the physician must watch over the patient's clinical state and the disease evolution towards recovery. He must diagnose the drug side effects, the postoperative complications or the appearance of an iatrogenic disease.

The whole decision process is represented by a finite state automaton, depicted in Figure 2, which triggers in turn each clinical module and thus coordinates them.

3 The Medical experience: storing and retrieving cases

Case-Based Reasoning (CBR) is a powerful concept that provides an analogic reasoning mode in problem solving [Aamodt/Plaza 94]. This capability allows CBR to express previous medical experience knowledge and thus to use it to enhance the diagnosis, prognosis, therapeutic and patient follow-up. The basis of CBR is that, by comparing new cases with previously stored, indexed clinical cases, and retrieving those cases that are similar, we can apply the corresponding decision and actions to the present patient, expecting that what was good one time, will be good several times [Gupta 94] [23]. The CBR approach includes the appropriate steps to deal with analogic reasoning.

Two main functions are provided: case storing through the "*new case indexation module*" and "*case retrieval*" handled by the so-called module in Figure 3. These two complementary features implement the CBR cycle.

The case base contains patient cases composed of diagnosis, prognosis and therapeutic facts. Figure 3 describes the main steps of the CBR cycle.

During the case retrieval stage, the CBR module computes structural similarities between the composite objects representing previously stored cases and the new clinical case under consideration.

A decomposition process of the case composite object provides sub-objects representing the following features: the problem definition and goal (PG), the environment representation (E), the reasoning protocol (RP), the applied decision (D), the necessary actions (A), and the actual result (Rs). During the case indexation stage, the new object case is instantiated and provided with diagnosis, prognosis and therapeutic components. The user must supply information that concerns the case

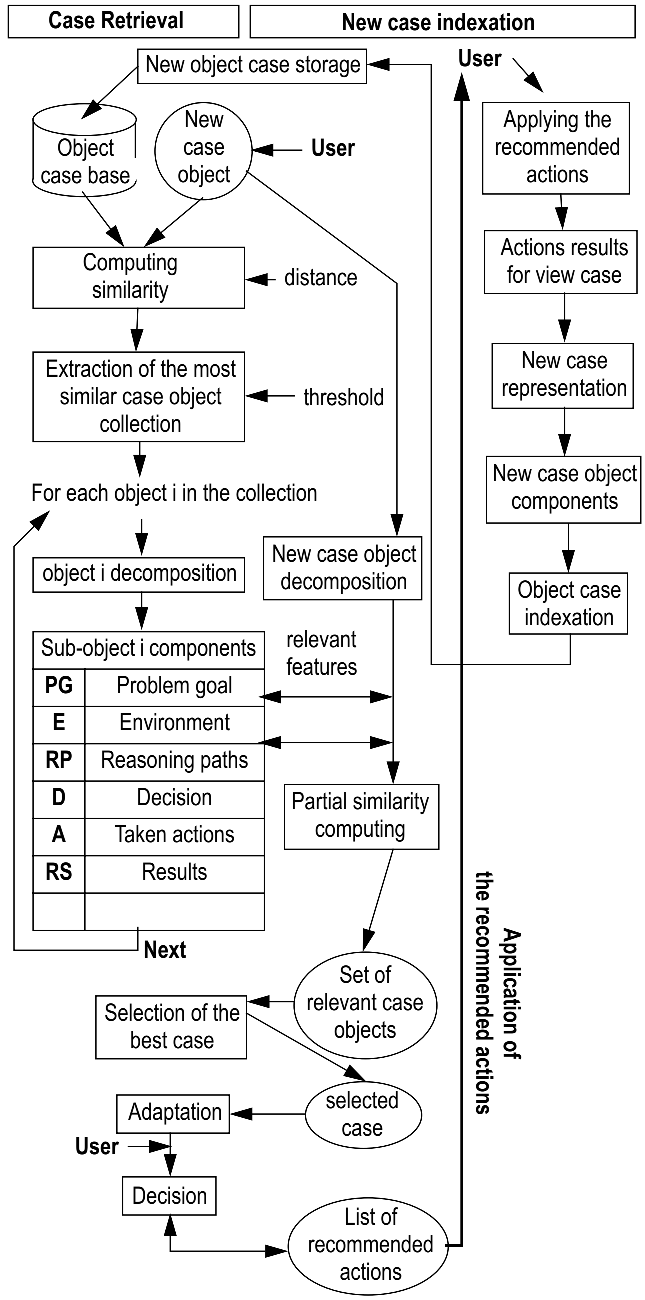
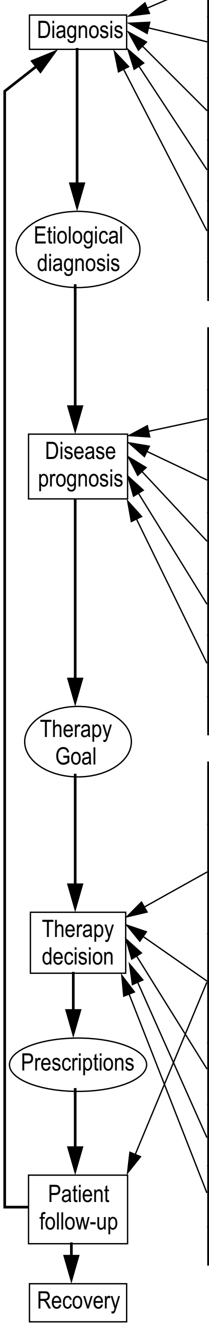


Fig. 3: The CBR cycle

features and circumstances {PG, E, RP, D, A, Rs}. Then the new case is indexed and stored in the case base. The process is depicted on the right side of Figure 3.

An application of the model to epilepsy diagnosis and therapy is available in [Colloc/Bouzidi 00].

Indexation of cases relies on a distance computation. Different distance models can be used to sort the cases: such as fuzzy logic [15] and the theory of evidence [Schuster et al. 97]. However, this topic is not within the scope of this paper and is therefore not further described.



Decision knowledge chunk	DSS	Data& Knowledge Sources
Patient clinical states, antecedents, history	S1	Patient record
Semiology knowledge	S2	Medical academic knowledge
Epidemiology data	S1	Epidemiological studies
Previous diagnosis experience	CBR	Previous disease cases
Diagnosis decision method	FSA	Supervisor: Finite State Automation

Decision knowledge chunk	DSS	Data& Knowledge Sources
Patient clinical current state evaluation	S1	Patient record
disease evolution expert knowledge	S2	Disease knowledge base
Disease statistical data	S1	Epidemiological studies
Previous same disease case experience	CBR	Previous disease cases
Prognosis evaluation method	FSA	Supervisor: Finite State Automation

Decision knowledge chunk	DSS	Data& Knowledge Sources
Patient antecedents, current prescriptions, contraindications laboratory results	S1	Patient record
Drug indications, contraindications, interactions, toxic and adverse effects	S2	Pharmacology, pharmacokinetic data & knowledge
Drug testing statistical data	S1	Drug testing studies
Drug prescription experience	CBR	Previous prescription cases
Therapy decision method	FSA	Supervisor: Finite State Automation

Fig. 4: The clinical DSS architecture and sources

4 A decision support system framework

4.1 The clinical decision process supervision

The purpose of our system is to integrate quantitative with qualitative decision methods. Most of the existing systems are based on only one of these two kinds of methods. To achieve this goal, some authors have proposed a flexible architecture which uses a Multi-Agent System (MAS) [Wiederhold 92] based on a communication language like KQML [Finin et al. 93] and a negotiation protocol like the contract net protocol [Jennings 93].

A MAS is an interesting solution to build such a decision support system but it is much more difficult to implement and to control. Our system uses a Finite State Automaton (FSA) which represents the states and transitions depicted in Figure 2 and triggers the appropriate procedures. This approach is similar to a supervised system [Schuster et al. 97]. The FSA describes the module interactions but it does not represent the data and knowledge flows. Some states are intermediate states and others represent a decision step final state.

4.2 Integrating the data and the knowledge sources in a decision cycle

For each clinical decision step, data and knowledge sources are necessary. Some of the data are provided through the interface by the user, others are stored in databases or knowledge bases. These information sources are displayed on Figure 1 in the subsystems 1, 2 and 3.

Figure 4 depicts the required knowledge chunks to achieve the decision, with the corresponding decision subsystem and the data or knowledge sources.

The small arrows in Figure 4 represent the relationship between the knowledge chunk and the decision step. The big arrows show the decision step succession and their results. Different data and knowledge sources are represented with different models but they must share a common interface. One solution is to use a multiagent system with an ontology that allows the DSS to share the same terminology. The agent is used to encapsulate the DSS module and to manage the communication and the negotiation between the agents in the system. Another solution is to use an object oriented approach to encapsulate the DSS modules and thus to inherit a general interface which allows them to communicate between each other.

The CBR module achieves transaction and clinical case recording. It must index and store the already-solved clinical cases coming with the knowledge chunks that were used to provide a solution. The environment consisting of the facts, events and especially the results, must also be stored. The main CBR drawback is that at the beginning of system use, the case base is void or contains very few cases. This gives no chance to find a case close to the one under consideration.

5 Conclusion

We showed that different kinds of DSS models, data and knowledge are complementary, and that they may all be useful to the determination of an appropriate decision in a complex domain like medicine. We have presented a framework to cope with the different decision paradigms integration. The system's supervision is managed by a finite state automaton that triggers queries to the appropriate database and knowledge base. We don't believe that a DSS can be implemented by a stand-alone CBR. This would require actual cases from the human being experience (patient records) be represented and stored from scratch; which is very difficult. We prefer an integrated approach involving knowledge and databases, which allows the initial priming and the ongoing enrichment of the case base. This process actually achieves a learning system. All these reasons justify the implementation of an integrated approach involving the different sources of information: KB, DB and CBR, to deal with the decision process. The coordination is done through a multi-agent system. A supervisor agent is implemented by a FSA that triggers the appropriate modules at each stage of the decision. It can be achieved with a syntax analyser like Yacc and the resulting C function is incorporated in a base class and then inherited by Java or C++ object classes. The main advantage of this approach is the system modularity. Therefore, the system can be built up incrementally. This increases system flexibility and feasibility.

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Bioinformatics and Health: Impacts of the Human Genome Project on Health Informatics

Fernando Martín Sánchez

Medical Informatics, defined as the application of information technologies to the management and analysis of clinical information and bioinformatics, resulting from the union of Computer Science and Genetics, have been independent disciplines with methods, objectives and well differentiated curricula. However, with the advance the Genome Project and the association of our genes with the causes of the diseases, we are witnessing the integration of clinical information and genetics in different environments, from basic research to clinical practice and public health. In this work the convergence between Bioinformatics and Medical Informatics is described as also the technologies that will make it possible and the main applications of these new focuses and its potential impacts in health.

Keywords: Bioinformatics, Medical Informatics, Genomics, Biochips, Diagnosis, Pharmacogenomics, electronic clinical record.

Introduction

Biomedicine, an information-based discipline, is undergoing profound changes as the new experimental approaches generate enormous volumes of unprecedented data (Genome Project, clinical trials, medical images). Biology and medicine are increasingly looking for support from the application of the information sciences and technologies.

The huge amounts of information generated by the new genetic technologies are gradually released to the scientific community, mainly over Internet, and have to be integrated and analysed in order to extract biomedical knowledge useful for the development of new diagnostic and therapeutic solutions.

As the Human Genome is deciphered and the knowledge about diseases is associated with the genes involved in their development, it becomes increasingly clear that the integration of genetic and clinical information is going to change the face of medicine in the coming years.

This paper outlines the main issues related to genetic information processing (bioinformatics) and clinical information processing (medical informatics) and indicates how the two are converging into what could be termed biomedical informatics, analysing the main impacts of the Human Genome Project on the development of information systems for health professionals.

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The Human Genome Project

The discovery of the of the DNA (deoxyribonucleic acid) molecule structure by Watson and Crick in 1953 triggered a scientific revolution in biology and opened the door to what is now known as molecular genetics.

Information is stored in living beings as packets or quanta termed genes. A gene is a portion of genetic material that encodes the information required to create molecules that are to fulfil particular functions within cells. The information present in genes is used for protein synthesis. As a simile with computer sciences, DNA could be compared with the source code of computer programs, whereas the proteins would be the executable programs.

Genomics is the branch of biology pursuing the study of the genomes of organisms. A genome is defined as all the genetic information present in a given organism. The Human Genome

Figure 1: The Human Genome Project

Project (HGP) is an international project that aims to build detailed physical and genetic maps of the genome of our species and identify the full sequence and location of the genes of which the genome is composed.

The scientific community is now setting new goals, which include using the huge amount of structural information generated so far in the development of functional analyses. So, what we are now witnessing is the transition from Genomic to the Post-Genomic Era, where the genomes and the relationships between their structure and their function will be analysed and compared.

The Human Genome Project (see Figure 1) is expected to be useful as a source of knowledge for understanding biological phenomena and diseases and lead to new methods of diagnosis, drugs and treatments for genetic-based diseases.

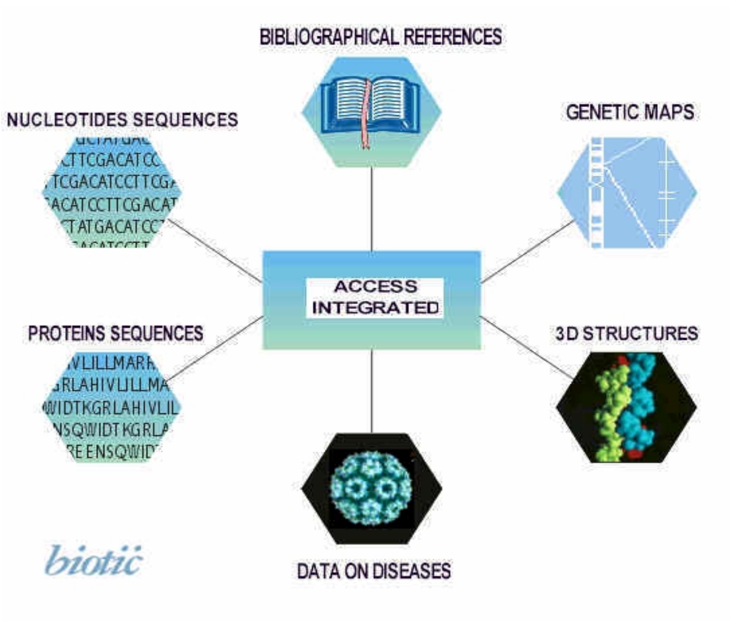

Figure 2: Integrated access to biomedical information

Bioinformatics

Bioinformatics is a relatively recent term and has not appeared in the literature before 1991 [Boguski 98]. Bioinformatics lies at the crossroads between the life and information sciences, providing the tools and resources required to promote biomedical research. It is an interdisciplinary scientific field, whose goal is to research and develop systems that are useful for giving an understanding of the flow of information from genes to molecular structures, their biochemical function, their physiological behaviour and, finally, their influence on diseases and health.

The main stimuli for the development of this discipline were the enormous volume of genetic data generated by all the genome projects (human and of other organisms), the new experimental biochip-based approaches, which output genetic data at high speed, and the development of Internet and the WWW, providing universal access to biological information databases.

The most prominent applications of work in this area are:

- Biological information databases
- Sequence alignment and comparison
- Protein structure and function prediction
- Genetic and metabolic maps
- Polymorphism and gene expression data analysis
- Phylogeny and evolution studies

The main challenge for bioinformatics is to provide a response to the avalanche of data from genomics. Whereas the results of experiments could be interpreted by means of a laboratory log only a few years ago, databases and data visualisation techniques are now needed to merely store and commence their analysis. Bioinformatics is evolving from just a series of techniques towards a full-blown science, as it provides the analysis component for understanding genomics and integrating genomic data (see Figure 2) to create predictive models of biological systems.

Biochips or DNA chips

Biochips are miniaturised devices with a high density integration of biological material located in an array, providing a means of rapid and efficient genetic analysis. They are called chips by analogy with the high density electronic circuits present in a microelectronic chip. They are having a big impact on research and have great clinical potential. They can be used to get individual genomic material and have the potential of providing a means of portable, rapid and economical diagnosis, which could be applied at the point of health care itself. [Martín 98].

Biochips are divided into small cells, each of which acts like a test tube where a reaction takes place. There are a huge number, as many as hundreds of thousands, of cells. Thanks to the extreme miniaturisation of the system, it is possible to analyse all the possibilities of mutation of a gene simultaneously on one chip or detect which genes are expressed at any time. The chip is put into contact with a fluorescent marked sample and is then washed, after which only the fragments of DNA that hybridise complementarily will remain linked. The chip is then

Figure 3: Images related to the use of DNA chips (Source: Affymetrix – BIOTIC)

entered into an optical scanner for the process of development, which will locate the strings marked with the fluorochrome (see Figure 3). A computer analyses the information from the scanner and outputs the result. (Wallace 97).

Individual genetic polymorphism

The sequence obtained thanks to the genome project will be a general sequence of the human species, as it corresponds to only the few people whose genetic material has been sequenced. However, the genetic make-up of different individuals is thought to be diverse, as a result of mutations and polymorphisms that amount to around 0.2% of our genome. It is precisely these differences that are very much related to people being more or less susceptible to developing diseases or to the varying therapeutic action of drugs.

Rapid sequencing systems can be used to examine all the possible polymorphisms and detect mutations in complex genes. The sequences of one and the same gene can vary from individual to individual, leading to a mutation. SNPs (single nucleotide polymorphisms) are caused by the mutation of a single DNA residue and can lead to a loss of gene function, a disease or to the acquisition of susceptibility to a disease.

The meaning of the variation of human genetics is analysed by observing the mutations of sequences of normal genes, which are then correlated with certain diseases or specific drug-response patterns.

Medical Informatics

Medical informatics is over 40 years old and has developed from a technology into a basic medical science. It includes the theoretical and practical issues related to the processing and communication of information derived from medical processes and related to health. It overlaps with almost all the medical specialities to configure a multidisciplinary sector with branches in epidemiology, technology evaluation, health economics and management and medical ethics.

Some of its main lines of development are:

- Computerised clinical records
- Education
- Hospital information and documentation systems
- Signal and medical image processing
- Knowledge-based systems for diagnosis and treatment support
- Surgery and radiation planning and simulation
- Health statistics and indicators
- Telemedicine
- Vocabulary, disease coding and procedures
- Evidence-based medicine support
- Epidemiology and public health system support

Emerging technologies

Interest of the big information and communications technology companies in bioinformatics

The major information and communications technology companies have decided to take a stake in the development of bioinformatic solutions for the future. They are building bioinformatic solutions centres or entering into cooperation with leading organisations or research centres in the field.

Compaq supplies Celera Genomics, which has completed the Human Genome Project sequencing, with its information technology infrastructures, allowing the company to use the Internet and electronic commerce to distribute its findings to the scientific community. Compaq has also supplied the Sanger Centre, a public institute located in Hinxton in the United Kingdom and which has sequenced 30% of the human genome and the genomes of a range of micro-organisms, with hardware.

IBM pursues its research activities in biological computing at its *T.J. Watson Research Center* in Yorktown Heights, New York. It has also entered into co-operation with the *Hospital for Sick Children* in Toronto, Canada, providing equipment for the *Genome Database* (GDB), one of the databases most extensively used by researchers from all over the world. IBM has announced an investment of $100 million earmarked for advanced sequence analyses and identifying proteins using the *Blue gene* supercomputer. IBM has also entered into agreements with bioinformatics companies like SBI (Structural Bioinfo) or Netgenics, which apply these new technologies to drug discovery.

SUN, again, has taken an interest in the intersection between biomedicine and informatics, launching the *Discovery Informatics Program* initiative, in which it is co-operating with a series of other companies (DoubleTwist, Curagen, GCG, Lion, Informax, Timelogic).

Silicon Graphics (SGI) has had strong links with the industrial and academic bioinformatics community for some time.

Motorola Inc. has signed an agreement with the Packard Instruments Company and Argonne National Laboratory to market and sell advanced biochips. Also Agilent (a subsidiary of Hewlett Packard) has announced an important initiative in the field of the health sciences: the genetic microarrays program (DNA arrays or biochips). Agilent markets a DNA and RNA-based bioanalyser Lab-Chip, developed jointly with Caliper. The bioinformatics platform that is to be used is based on the Rosetta Inpharmatics *Resolver* expression data analysis system.

The most promising computer technologies in this sector are described briefly below.

Data mining and visualisation

Together with new experimental approaches, the appearance of new technologies for outputting genetic information has led to the generation of huge quantities of data that must be managed and stored for later analysis using bioinformatics tools. This new challenge has led to the development of new methods, tools and to the application of data mining. Data mining involves extracting the predictive information that is latent in large databases. Several techniques and methodologies, including decision trees, clustering techniques, rule induction, neural networks and genetic algorithms, are used for this purpose. The models produced by this modelling or predictive work are visualised by means of special-purpose tools that employ a range of methods to ease their understanding.

Internet portals, e-genetics and e-health

Bioinformatics was one of the first scientific and technical disciplines to make use of the features of Internet-based systems to develop solutions and provide for data sharing, software distribution and co-operative work between groups and scientists [Brown, 2000].

With the explosive growth of the Internet and the completion of the first phase of the Human Genome project, there is a trend, running parallel to electronic commerce in other branches of activity, towards the appearance of Internet portals that give researchers accessibility to genetic data and bioinformatic tools. Craig Venter, leader of Celera Genomics, recently said that he manages an "Internet Company". Other big bioinformatics and genomics companies make their data and software, formerly reserved to their customers, available to universities, small and medium-sized companies and researchers through web interfaces, working as ASP (Application Service Provider), in some cases with commercial criteria. Additionally, these services are viewed by the large pharmaceuticals and biotechnological industries as the possibility of "outsourcing" bioinformatics so as not to have to make an enormous outlay in specialised technology and human resources [Fisher, 99].

Again, there are initiatives in the field of genetic diagnosis for the development of teleconsultation services by means of biochips over the Internet, or capturing patient genetic material for research purposes from medical Internet portals. Some are already predicting that in a few years people will be able to ask a laboratory for their genetic profile on a CD-ROM and compare this with web-based genetic libraries that will be able to inform them of their likelihood of suffering certain diseases or of the drugs they tolerate best.

Database integration, CORBA, components technology

The size of biological databases is growing at an exponential rate. The management of these resources and their use by scientists is becoming a far too complex task. Genetic databases are organised and structured very differently, although they often contain interrelated data. Some are supported by standard relational managers, while others are composed of plain-text files. One evident technological challenge is to integrate these sources of information, thus providing for their unified access irrespective of any changes of organisation they undergo.

CORBA and Java provide interoperability and portability in respect to Internet-based database access. Component-based technologies are valuable in that they can be used to extend bioinformatic applications across networks, operating systems and different programming languages, providing developers and users with a guarantee of scalability, maintenance and ease of use.

XML

There are over 600 databases of interest for genomics researchers. Many provide not only data but also services. Taking into account the differences there are in interfaces, syntax and semantics, it is almost impossible for a user to be able to use any databases of interest all at the same time. One of the biggest challenges of bioinformatics is to respond to the continuous growth and changes to these databases.

XML (eXtensible Markup Language) is a programming language that has emerged as an evolutionary successor to HTML and is put forward as the candidate technology for interconnecting all these sources of knowledge. It is used to describe the content of a document and has been designed as a SGML (Standard Generalized Markup Language) application, which makes it possible to create specialized documents. XML is suitable for any type of data description, which means that XML-based information systems can be used to create, store ad distribute information. An XML-based information system can contain different document type definitions (DTDs), which are formal document grammars, and users can, therefore, create documents that comply with particular DTDs.

Several XML-derived languages have appeared in bioinformatics: BIOML (BIOpolymer Markup Language) is a DTD for sequence and structure data in molecular biology, BSML (Bioinformatics Sequence Markup Language) is another DTD, which is used to represent molecular biology data, and MAML (Microarray Markup Language) for standardising gene expression data obtained with microarrays.

Knowledge management and ontologies

A conceptualisation is an abstract entity, which acts as a simplified view of the world that is to be represented for a purpose. Any knowledge-based system implicitly or explicitly includes a conceptualisation. An ontology is an explicit specification of a conceptualisation, that is, a description of the concepts and relationships that actually or possibly exist for an agent or a community of agents. Formally, an ontology is the establishment of a logical theory.

There is an important line of research for identifying technologies of use for managing knowledge and interchanging concepts and representations in biomedical sciences (Common Ontologies Exchange Language, genomic ontologies, drug research and development ontologies). This is of capital importance for organising the mass of knowledge generated daily on any subject of biomedical research.

Genomic impacts on clinical practice and health research

The application of genomic technologies (bioinformatics, biochips, etc.) and available biomedical knowledge is leading to the development of new approaches in the field of biomedical research, which are expected to be used in clinical practice in the coming years. Three of these application environments are outlined below.

Clinical diagnosis

The capabilities of the new tools used in genomic research are likely revolutionise clinical practice when applied as diagnostic tools. These high-performance new devices (biochips) enable a large number of parameters that can be used as diagnostic markers to be monitored simultaneously. This will have a big impact on the methods of genetic analysis. [Collins 99]. Around 6,000 genes associated with various diseases are known today and the list of genetically based diseases gets longer all the time.

Genetic analyses are used to identify a person is likely to suffer a disease, as well as to confirm a suspected mutation in an individual or a family. However, the growing interest raised by these field focuses on predictive analyses, which identify people with a high risk of contracting a disease before the associated symptoms appear.

Development of new drugs

Why do different patients with the same symptoms respond differently to the same drugs? Although the concept of individual variations on a molecular scale (pharmacogenetics) is not new (pharmacology has been addressing this problem from the toxicological viewpoint for 40 years), the technological platforms proposed for successfully implementing this concept have been developed in the last 4 years.

New technologies that ease the understanding of the role of genes in diseases is revolutionising the processes of new drug discovery and development (pharmacogenomics), providing the industry with substantial opportunities of saving time, cutting costs and lowering risks. The birth of personalised drugs for different strata of patients classed according to their genetic characteristics is near. The discovery of the genetic variants of individuals, which influence the effect of drugs, will enable the development of new diagnostic procedures and therapeutic products that will be selectively prescribed to patients with guaranteed safety and efficacy (Housman 98).

Genetic epidemiology

The use of new genetic information technologies will make cost-effective screening (genetic tests) possible at the population level. The challenge is to transfer the knowledge of genetics to the field of public health. For this purpose, it is important to assure the correct use of genetic information and new genetic information management technologies to produce health programs. There is talk of epidemiological/genetic study systems (associative genetics, genotype-phenotype population studies), and there are efforts aimed at disseminating genetic information, training health workers and developing policies that include the genetic knowledge output by the Human Genome Project in epidemiological practice.

The application of information technologies in this field can be helpful in carrying out cooperative efforts, like the HuGeNet (Human Genome Net) initiative, by the CDC's Office on Genetics and Disease Prevention [Khoury 98], to develop and distribute epidemiological information on the human genome, including:

- Specific prevalence data on genetic variants
- Epidemiological data on the relationship between genetic variability and diseases in different populations
- Evaluation of the validity and impact of genetic analyses.

Bioinformatics applications in health

Computer science has a fundamental role to play in the transfer of knowledge from genomics to health-care practice. The integration of genetic and clinical information, the training of health workers and patients and the support tools for managing all this new information is unthinkable without the use of information and communications technologies. The main field of application of bioinformatics, with its stock of genetic information processing and analysis, should be the clinical environment, although the most plausible hypothesis, as will be described later, is the convergence between medical informatics and bioinformatics.

Entry of genetic data into the computerised clinical records

The OMIM database contains over 6,000 genes associated with diseases. Genetic tests for several of these (Huntington's disease, cystic fibrosis, cancer) are already available. Although the analyses are now carried out in central laboratories and take several days, technologies can now transfer the genetic laboratory to the general practitioner's surgery, and even to the chemists'. This can be done thanks to the transition from PCR-based sequencing to new biochips, bringing us closer to the concept of an "automated clinical genotyping system".

With the advent and deployment of genetic information in routine clinical practice, associated tasks, like clinical records, will have to be adapted to be able to effectively manage this new type of information. The need for computer programs to assist in extracting, processing and managing these data will promote the inclusion of this information in clinical records. The benefits of including genetic information in clinical records are as follows:

- Application of medical knowledge to genetic sequencing for treatment
- Information sharing and transmission among practitioners
- Use in research – systems of associative genetics in epidemiology

Everything points to genetic information being routinely included in the computerised clinical records in a few years [Naser 98].

Genetic clinical practice guidelines

Another field in which the advent of genetic information is likely to cause a major impact is health management. Efforts will have to be made to develop new clinical practice guidelines and protocols, addressing genetic issues are included and to introduce new coding systems. Biochip-based technology can do for genetics what microprocessors did for computing. Thanks to the level of miniaturisation achieved, diagnostics will be able to move from the central laboratories into the practitioner's surgery, as computers left the computer centres and personal computers became ubiquitous. Clinicians are going to need regulated and negotiated procedures for developing the process of diagnosis and treatment. Computer science has been supplying excellent instruments for creating, disseminating and applying these clinical practice guidelines for years.

Continuous medical training

Biomedicine researchers and practitioners spend less and less time in the laboratory and library, while they increasingly use computers to store, interchange or analyse information. Even so, this convergence of biomedicine and computing is not reflected enough at universities and schools of medicine [Varmus 99]. If we acknowledge the quasi-ubiquity of the information communication and processing activities in medical practice, it is not difficult to appreciate how the progress made by these technologies can lead to qualitative changes in the way in which health care is provided. Therefore, the need to specially train practitioners in these subjects at undergraduate, postgraduate and continuous medical education has been recognised. No formal process of training practitioners in these subjects has yet been provided in this country, and everything seems to indicate that the information and communication technologies can provide a guarantee of continuous or on-the-job training, taking into account how quickly knowledge is updated in these fields.

Access of health workers to resources and genetic databases

Bearing in mind the enormous rate of genetic-based medical knowledge generation, it is not hard to imagine that physicians will be obliged to consult the Internet to locate up-to-date information required in routine practice (databases on genetics, diseases, scientific papers, clinical histories, epidemiological data, information on drugs, …) in a few years' time [Sikorski 97].

One of the major challenges for bioinformatics over the next century is to manage to link clinical information with molecular information. One especially important point is the need to manage information at health organisations that are going to undergo drastic changes owing to the developments in molecular genetics [Altman 98].

The data handled by bioinformatics will pervade in medical practice, and the hospital information systems will have to be prepared to house all this new range of data.

Redefining and coding diseases

Diseases were first grouped according to patient symptoms, a classification technique that is still used. Later, as knowledge progressed, the results of the analyses that provide a better and more accurate definition of the disease-causing agent were added to the clinical symptoms. Thanks to the knowledge supplied by genomics-based medicine, this system may well be redefined, and diseases will stop being defined on the basis of the phenotype (external traits, symptoms) and be identified by the causal mechanism and the patient genotype. On this point, diseases have already been identified that used to be considered different and which have been found to have the same origin (two dystrophies that were thought to be of different origin and that share the affected gene). Additionally, it will be discovered that different diseases can be interrelated (the apoE gene is involved in causing cardiovascular diseases and Alzheimer).

Computer-assisted diagnosis systems

Clinicians will be faced with new decision arrays on the best treatment, in which they will have to consider individual genetic variations and the molecular subtypes of the disease.

	Disease Subtypes					
Patient Genetic Traits	X					
						X
				X		
		X				

Table 1: Decision array for personalised treatment

Thanks to approaches like this, it will also be possible to better monitor the therapies applied, and ascertain traits that have an impact on the treatment response and efficacy of the drugs and which could sometimes suggest they be changed or omitted. The diversity of human genetics causes population groups with given characteristics that make them more likely to suffer from some diseases than others. This is precisely what will enable pharmaceuticals companies applying pharmacogenomic techniques to develop personalised drugs and medicines that will better suit certain molecularly characterised population groups. Computer science has to provide assistant or expert systems to help physicians with this complex task.

Conclusions

The convergence of medical informatics and bioinformatics. Opportunities for co-operation

Searching for the keyword *Informatics* in MEDLINE, the reference database of scientific papers published in biomedical journals, 346 publications appear in the last five months. Of these, 175, that is, more than half, are on genomics. This is indicative the growing importance of work on bioinformatics in health [Kohane 2000].

Medical informatics and bioinformatics are growing closer, as information on the human genome is generated and linked with medical knowledge on diseases [Altman 00]. This trend is evident from the fact that medical informatics congresses like MIE, AMIA or MEDINFO have special sessions on bioinformatics and the masters in medical informatics at several universities, like Stanford, include bioinformatics training.

Although bioinformatics and medical informatics share many methodologies, data types and algorithms, it is noteworthy that bioinformatics is more advanced in: [Altman 98]

- Database integration technologies
- Data representation systems and algorithms
- Systems validation methods and hypotheses

Medical informatics has developed further in areas like (Miller, 2000):

- Reasoning systems
- Terminologies, coding and vocabularies
- User interfaces
- Knowledge representation
- Data mining
- Modelling and simulation
- Probabilistic methods

There are a quite a few areas of common interest, where there synergy could take place [Kohane 2000]:

- Data interchange format standardisation
- Components for distributed computing
- Image processing
- Organisation and access to scientific literature and sources of information
- Knowledge representation
- Data models
- Controlled vocabularies
- Processing of sources of data error and noise in signals
- Confidentiality and data security
- Interfaces for efficient data entry
- Knowledge discovery tools

Some examples of systems where the barrier between bioinformatics and clinical informatics is fuzzy are:

- Systems for processing individual genetic information and its role in disease development
- Integration of genetic information in clinical records and computer-assisted diagnostic decision-making systems
- Processing of data from biochips or DNA microarrays
- Pharmacogenetics databases [Altman 2000] (genetic information in clinical trials)

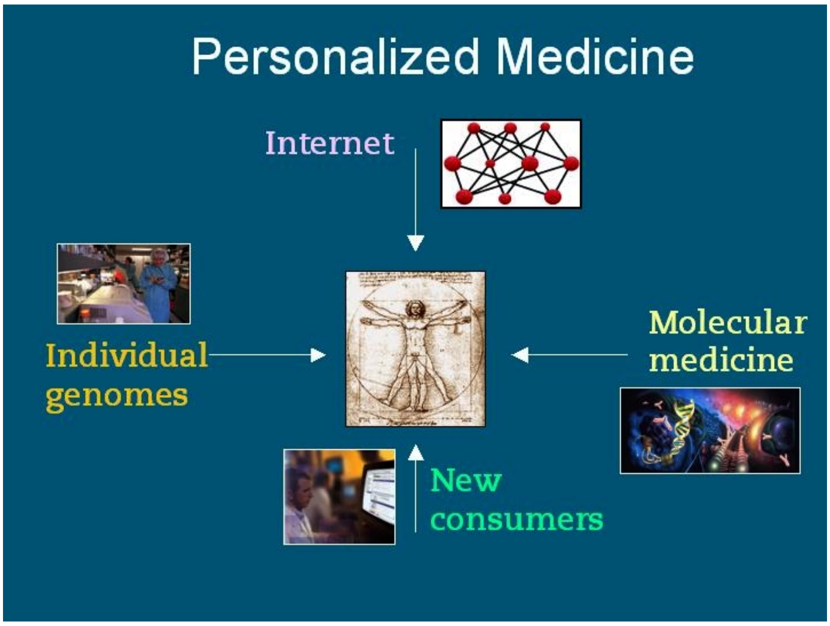

Figure 4: Factors supporting the development of personalised medicine

Personalised, preventive, molecular medicine

The main issues of what is likely to be a new revolution in medicine triggered by the introduction of genetic information and its integration into the clinical process have been presented. This could be characterised as:

- *Molecular* – We will witness the birth of what is known as “molecular medicine”. Molecular medicine can be defined conceptually as the effort to define both normal and pathological physiological states in terms of the presence and regulation of the molecular entities making up living beings.
- *Preventive* – Prevention in this sense means the medical actions taken in respect of the environment and life style, aimed at reducing the risk of genetically predisposed individuals suffering from diseases. Knowledge of the genetic traits of populations would make it possible to ascertain the likelihood of suffering from certain diseases before the symptoms appear, thus enabling the implementation of improved and genuine preventive medicine.
- *Personalised* – Several forums are pointing out the importance of genomics-based approaches to furthering the personalisation of medicine. The recently completed sequencing of the human genome opens up enormous possibilities for developing new diagnostic procedures, treatments and drugs that will be selectively prescribed to patients, with guaranteed safety and efficacy.

Three recent prospective reports on medicine coincide in pointing out the impact of genomics and the Internet on future health systems. The papers “HEALTHCARE 2000: A strategic assessment of the Health Care Environment in the United States”, “HEALTHCAST 2010” and “HEALTH and HEALTHCARE 2010, the Forecast, the Challenge” (see references), published almost simultaneously, give an understanding of the technological trends that are likely to have most impact on the health system in the coming years. The three reports stress especially the impact of genomics and biomedical informatics on the system of disease prevention, diagnosis and treatment. The development of personalised medicine (see Figure 4), adapted to the genetic particularities of patients and where diseases are classed according to their molecular cause, is one of the biggest challenges in the sector, and it is here that these techniques and methods are going to most useful. They will also contribute to the gradual transformation of palliative or curative medicine into genuine preventive medicine, where diseases can be detected and treated even before the first symptoms appear.

Ethical, legal and social issues

Despite their undeniable usefulness, studies of the genome involve some ethical risks that cannot be obviated and which must be carefully addressed. The private nature of genetic information raises serious obstacles to translating the knowledge of the human genome into benefits to the health of the individuals. In 1989, the very architects of the human genome project admitted that the information that would be obtained from sequencing the human genome and mapping genes would have profound implications for individuals, the family and society and established the ELSI program to anticipate and study the ethical, legal and social issues that would be raising as a result of research into human genetics. The Neufield Council was the main mover of the ethical debate in England. UNESCO has set up an International Committee of Bioethics and has promoted a Declaration on Genome-related Human Rights. The Council of Europe issued a report on the protection of human rights and the dignity of the human being with respect to biological and medical applications in 1997.

The migration of the new genetic technologies (microarrays) into clinical practice will make possible rapid and economic identification of people with a high risk of suffering a genetic disease in the near future. This is one of the most immediate challenges for the ELSI project. Before these technologies are applied, actions will have to be developed that assure the safety and quality of the tests and raise the knowledge of health workers concerning their benefits and risks. Additionally, patients must receive proper genetic advice by means of which to make a decision in full knowledge of its implications and individuals must be assured that the information will not be used against them or their families.

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Secure Internet-Access to Medical Data

Ulrich Ultes-Nitsche and Stephanie Teufel

This paper reports on context-dependent access control to support distributed clinical trials. Centrally stored data will be accessed from contributors to a clinical trial over the Internet. We present in this paper how context-dependent access control can be implemented on the Internet in a secure way, using Java Servlets to implement the access control and SSL to secure communication.

Keywords: Workflow-support for clinical trials, telemedicine, context-dependent access, health information systems.

1 Introduction

In [Holbein et al. 97] and previous papers [Holbein/Teufel 95], [Holbein et al. 96], the concept of a context-dependent access-control has been introduced and discussed exhaustively. In context-dependent access control, information about the state of a business process is combined with general knowledge about a user to grant or revoke access to sensitive data [Holbein 96]. A prototype implementation of the concept is described in [Nitsche et al. 98]. The prototype implementation is for local use only and would reveal many security holes if used over an open network. However, using technology different from the one presented in [Nitsche et al. 98] allows to come up with a secure distributed solution to context-dependent access control over the Internet.

In this paper, we present an implementation concept for context-dependent access control on the Internet. Even though applied to the specific application area of clinical trials, the underlying concepts are general and support all applications for which context-dependent access control is suitable. The paper summarizes a part of the Swiss National Science Foundation funded project MobiMed [Fischer et al. 95]. The system we are going to describe is PC-based (Windows NT) and implemented as a Java Servlet accessing an MS SQL Server database.

2 Context-Dependent Access Control

Role based security approaches fit well the hierarchically structured setting of a hospital [Ting et al. 91], [Ting et al. 92]. Each level in the hierarchy can be mapped to a so-called organizational role that a person at this hierarchical level plays in the hospital (e.g. medical staff, care staff, etc.). After an analysis of each role's demands on obtaining particular data to perform work, access rights are assigned to each role. The access rights determine which records in the database that contains information about the patients (patient records) may be read or written by a person playing a particular role. When logging in, a user of the system identifies her- or himself, ideally by using a chipcard and a PIN, and then a role is assigned to the person according to user/role lists, determining her or his access rights. A different way to handle role assignment is to store role information on the chipcard itself in ciphered form, which then is read during log in or, alternatively, whenever data records are accessed.

Simple role based access control mechanisms have the advantage that they can be implemented rather easily but the drawback of certain inflexibilities. A more sophisticated access control technique refining the role based approach takes into account an access request's particular point in time, i.e. the question: "Is it reasonable that a person playing a particular role needs access to certain data at the current state of a health-care process?" Obviously, it is not necessary to have access to all data about a particular patient all the time. The question of "what does one need to know?" moreover, "what does one need to know right now?" (at the time of an access request) is the context-dependent access control scheme that we consider in this paper. A possible realization of the need-to-know principle

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can be achieved by combining user role information with state information of a workflow ("Is it reasonable to grant access to a person (playing a particular role) in the given workflow state?").

3 The Access-Control System

As mentioned above, context-dependent access control combines user information with process state information to compute access rights. Since the database system that we consider – MS SQL Server – uses group-based access control, we have to build context dependency around group-based access controls.

Access rights in the context-dependent scheme are only given temporarily to users for a single access. Therefore we create a not yet existing group, called here MobiMedDBAccessGranted. No user and no group is assigned to MobiMedDBAccessGranted *initially and permanently.* In order to change the group membership of a user temporarily, we use the SQL stored procedure sp_change_group. After checking the "need to know" of a user to perform an access [Holbein et al. 97], he or she receives temporary membership in group MobiMedDBAccessGranted, the access is performed, and the user is reset to her/his group.

As context information we use state information from a business process model. In such a model, a state represents the history of the process. To each patient a single instantiation of the business process is created. The process ID of the instantiation is used as a unique key to all database entries related to the patient. Context-dependent access-control tables are generated, containing quadruples (stateID, groupID, table_entry, access_type), indicating that in state stateID, a user belonging to group groupID can access database entry table_entry by an access of type access_type. Access types are e.g. *full access*, *read-only access* or *no access*. The presented access-control concept can be implemented on the Internet around Java Servlets and SSL.

4 Java Servlets

The past year has seen the rise of server-side Java applications, known as Java Servlets. Servlets are used to add increased functionality to Java-enabled servers, replacing CGI and offering many significant advantages [Sun Microsystems 98] (we focus on security here):

4.1 Portability

Java Servlets are protocol and platform independent and as such are highly portable across platforms and between servers.

4.2 Performance

Unlike CGI scripts, Servlets do not create a new process for each incoming request. Instead, Servlets are handled as separate threads within the server, reducing object creation overhead.

4.3 Security

The Java language and Java Servlets have improved security over traditional CGI scripts both at the language level and at the architecture level:

4.3.1 Language Safety

As a language Java is type safe and handles all data types in their native format. With CGI scripts most values are treated and handled as strings which can leave the system vulnerable. For example, by putting certain character sequences in a string and passing it to a Perl script, the interpreter can be tricked into executing arbitrary and malicious commands on the server.

Java has built-in bounds checking on data types such as arrays and strings. This prevents potential hackers from crashing the program, or even the server, by overfilling buffers, which is commonly known as stack smashing and can occur with CGI scripts.

Java has also eliminated pointers and has an automatic garbage collection mechanism, which reduces the problems associated with memory leaks and floating pointers. The absence of pointers removes the threat of attacks on the system where accesses and modifications are made to areas of server memory not belonging to the service process.

Finally, Java has a sophisticated exception handling mechanism, so unexpected data values will not cause the program to misbehave and crash the server. Instead an exception is generated which is handled and the program usually terminates neatly with a run time error [Garfinkel/Spafford 97].

4.3.2 Security Architecture

Java Servlets have been designed with Internet security issues in mind and mechanisms for controlling the environment in which the Servlet will run have been provided.

CGI scripts generally have fairly free access to the server's resources and badly written scripts can compromise the security of a server by either leaking information about the host system that can be used in an attack, or by executing commands using untrusted or unchecked user arguments. Java significantly reduces these problems by providing a mechanism to restrict and monitor Servlet activity. This is known as the Servlet sandbox. The Servlet sandbox provides a controlled environment, in which the Servlet runs, using a security manager to monitor Servlet activity and prevent unauthorized operations.

In JDK 1.2 an extension to its security manager, the access controller, is introduced. The idea behind the access controller is to allow more fine-grained control over the resources a Servlet can access. For example, instead of allowing a Servlet to have write permission to all files in the system, write permission can be granted for only the files required by the Servlet for execution [Hunter 98].

However, Java-based servers are still vulnerable to denial of service attacks where the system is bombarded with requests in order to overload the server resources. However, the effects of this can be reduced by specifying an upper limit on the number of threads that can be run concurrently on the server. If all the threads are allocated, that particular service can no longer be accessed, but because the server still has resources left to allocate, the rest of the services are still available.

5 The Secure Sockets Layer Protocol

The secure sockets layer protocol (SSL) is designed to establish transport layer security with respect to the TCP/IP protocol stack. Version 3 was published as an Internet draft document [Freier et al. 96] by the IETF (Internet Engineering Task Force). In combination with Java Servlets, the use of SSL is studied in [Ultes-Nitsche 00].

Unlike other concepts that secure connections or even only data-packages, SSL includes the concept of a secure session, determined by the parameters negotiated at the beginning of the session by the two protocol machines. It is this session concept that makes it appealing for being used in the MobiMed prototype. The secure session lasts as long as a user is logged in the system. Since communication with the user will be based on HTML documents sent to and received from the client side using http, the use of SSL will be transparent to the user.

6 Implementing the Access-Control System

In order to perform the SQL stored procedure sp_change_group, the Servlet is equipped with SQL Server administrator privileges. The Servlet offers the only way to access the MobiMedDB database and can be accessed from any application on the Internet. By putting the SQL Server administrator information into the private part of the Servlet class, it is securely protected.

Java Servlets support the Java DataBase Connectivity (JDBC) API to access databases that support the JDBC API, too. SQL Server supports the Open DataBase Connectivity (ODBC) API that can be linked to the JDBC API. The interfaces within the resulting system are presented in Figure 1.

The client-side application talks to the Servlet via the webserver. The connection between client and web server is secured using SSL. The Servlet API handles http get and post requests. From the SQL Server it receives user information as well as the access-control tables for the evaluation of access rights. The Servlet handles user log-ins as well as setting and resetting group membership. An example of a successful request under the context-dependent access control scheme is described in eight steps in Figure 2 (AW Administrator is the runtime environment of the workflow system):

1. The user (application) sends an access request to the Servlet.
2. The Servlet requests and receives context information about the workflow of the patient whose record is attempted to be accessed.

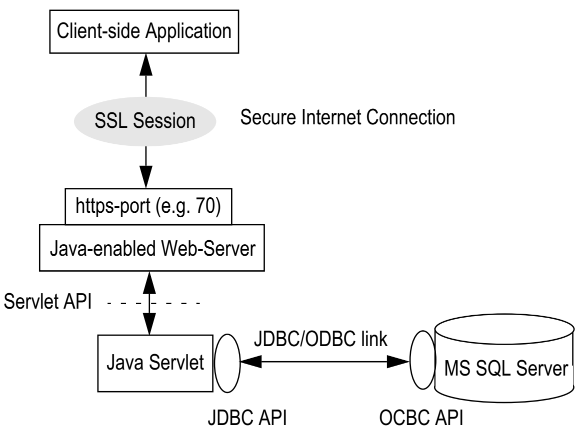

Fig. 1: The system inferfaces.

3. The Servlet requests and receives group information about the user who is requesting the access.
4. Both, context and role information are combined and the authority of the access is evaluated. Subsequently it is assumed that the user has authority to perform the request (otherwise the request would be rejected at this point).
5. The user is set temporarily to group MobiMedDBAccess-Granted.
6. The request (query) is performed on the database MobiMed-DB.
7. The results of the query are delivered to the user.
8. The Servlet resets the user to his/her previous group membership.

7 Discussion

To ensure privacy, the SQL Server and the Java-enabled Web server, including the access-control Servlet, must form a single system in which only the Web server is accessible remotely. Data exchange between client and server is confidential by using SSL. SSL also supports authentication of client and server.

Given that the access-control system is implemented as described, the obvious major threat to the system is that the administrator log-in procedure known to the Servlet becomes publicly accessible. By hosting the sensitive parts of the access control in a private method of the Servlet and taking into account that Servlets are server-side Java bytecode, neither can a user access the private Servlet methods directly nor is bytecode containing sensitive information accessible from the Internet. The sensitive parts of the system are hence securely kept.

A way a user could try to break the system is by sending multiple access requests, knowing that at least for some of them she/he has authority. The idea is that a request for which she/he has no authority coincides sufficiently in time with a request for which she/he has authority. So both queries could be send to the SQL Server at the time when she/he is temporarily assigned to the group for which access is granted. This situation can only occur, when multiple threads of the access-control Servlet are not synchronized properly. The simplest attempt to solve this problem is to disable multi-threading for single users.

Since accesses to the system are relatively rare compared to heavily used Internet servers, performance is not very much an issue in our case. Tests with an early local prototype [Nitsche et al. 98] and a similar system [Röhrig/Knorr 00] did not show any problems with performance.

It should be noted that in the setting of a hospital, access to data can be vital. Therefore context-dependent access control will be equipped with simple, group-based bypass mechanisms for emergencies. However, bypassing the context-dependent access control will have to be logged thoroughly to provide proof of potential misuse of the bypass mechanism.

8 Conclusion

In this paper we reported on a project on context-dependent access control to support distributed clinical trials. We concentrated on presenting the technical aspects of the solution, in

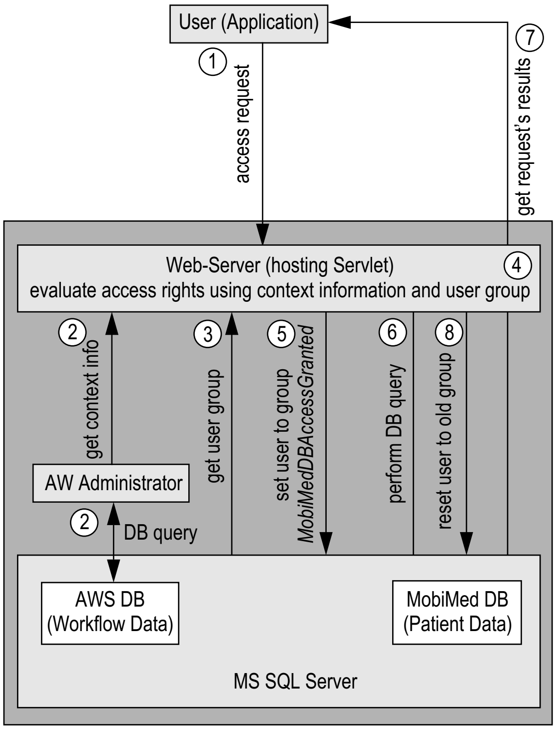

Fig. 2: The events comprising a successful access request.

particular on the use of Java Servlets. The implementation concept comprises a secure distributed solution to context-dependent access control [Nitsche et al. 98], [Röhrig/Knorr 00] over the Internet. The proposed system is PC-based (Windows NT/ Windows 2000), using a Java Servlet to access an MS SQL Server database (that contains the medical data) in a context-dependent fashion. To secure the communication the secure sockets layer protocol (SSL) is used. The underlying security concepts presented here are general and in particular the Internet security issues can be adapted to different platforms [Ultes-Nitsche 00] and applications [Hepworth/Ultes-Nitsche 99] without change.

Acknowledgements

We thank Prof. Dr. Kurt Bauknecht and the SNSF for their support and Konstantin Knorr for helpful comments on an earlier version of this paper.

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Data Warehouse Dissemination Strategies for Community Health Assessments

Donald J. Berndt, Alan R. Hevner, James Studnicki

The Comprehensive Assessment for Tracking Community Health (CATCH) methodology provides a systematic framework for community-level assessment that can be a valuable tool for resource allocation and health care policy formulation. CATCH utilizes health status indicators from multiple data sources, using an innovative comparative framework and weighted evaluation process to produce a rank-ordered list of critical community health care challenges. The community-level focus is intended to empower local decision-makers and provide a clear methodology for organizing and interpreting relevant health care data.

Keywords: Data Warehousing, OLAP (On-Line Analytical Processing), Health Care Informatics, Decision Support Systems, Database Systems.

1 Community Health Organizations

It is well documented that considerable variation exists in the health status of defined populations. This variation is evident when we compare large population groups, such as separate nations, states, or regions within a single country. Surprisingly, variation often persists within smaller population groups, such as census tracts or zip codes inside United States counties. These variations exist not only for what would be considered epidemiological health status outcomes (i.e., morbidity and mortality rates), but also for indicators which could be considered other dimensions or domains of population health such as socio-economic and demographic characteristics, the availability of health resources, patterns of health behaviours, and many other factors. In order to improve the health status of populations, a continuous monitoring and improvement system must be implemented. Such a system requires a comprehensive, objective, and uniform methodology for defining and characterizing the many dimensions that comprise the health status of a community.

As part of the on-going clarification of the public health role at the community level and the transitions from a *disease* to a *health* focus and from a *treatment* to a *prevention* strategy, there has been recognition that partnerships and collaboration are necessary to support effective action [Institute of Medicine 96], [Nakajima 97]. Health organizations, public sector agencies, medical care providers, businesses, the religious community, educational institutions, and other community organizations are interdependent components of a multi-sectoral community health organization. The overall community must be empowered to make the necessary, and sometimes difficult, resource allocation choices to improve health through information, education, behaviour change, and social support [Cropper 96]. Such collaborative action at the community level must be informed by *unbiased data* describing the community's health

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This research is partially funded by the U.S. Dept. of Commerce through a Technology Opportunities Program (TOP) grant.

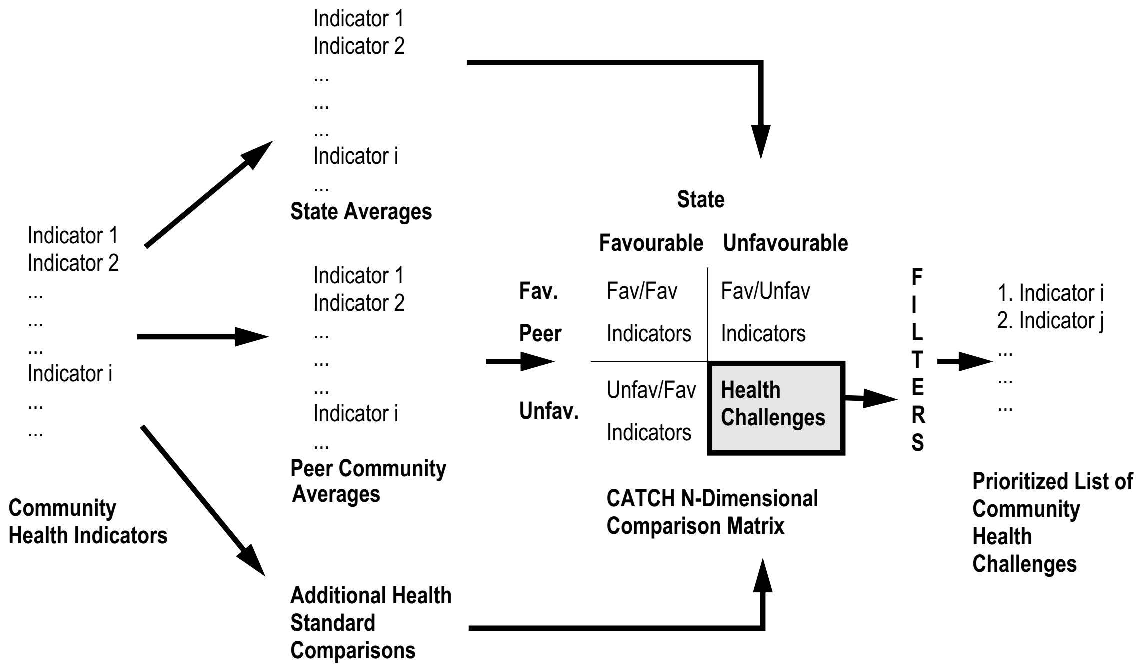


Fig. 1: The CATCH Methodology

status, needs, and resources. The ability is also needed to track progress over time to meet the community's health care goals.

The gap between current practice in community health care spending and the above goals of collaborative community health care decision-making is vast. The availability and quality of data on health indicators are problematic. There is little empirical evidence on the use, sharing, or strategies to integrate health data into decision-making to provide guidance to community health organizations. While most of the literature on collaborative leadership and community engagement focus on the process [Centre of Disease Control and Prevention 97], [Chrislip/Larson 94], little attention has been focused on the effect of the availability of a common set of data, such as the community health profile, on the quality and inclusiveness of decision-making. There is also scant information about the use of data and information technology to support and monitor the process.

The purpose of this paper is to present an outline of the Comprehensive Assessment for Tracking Community Health (CATCH) methodology and its implementation in a data warehouse. The various modes of data dissemination from the data warehouse to the community are explored and examples of current CATCH interfaces are demonstrated. We conclude by examining important issues of community decision support on health care.

2 The CATCH Methodology

The University of South Florida's Centre for Health Outcomes Research has developed the CATCH methodology to provide comprehensive, objective health status data for community health planning purposes. CATCH collects, organizes, analyses, prioritizes, and reports data on 225 health and social indicators on a local community basis. The CATCH methodology has been tested, refined, and validated over the past nine years. Reports have been prepared for 15 U.S. counties both within and outside of Florida.

The CATCH methodology can be briefly described as shown in Figure 1. Community health indicator data are gathered from a variety of sources. Secondary data sources include health care data reported by hospitals, local, state, and federal health agencies, and national health care groups. Primary data sources would involve data gathered from door-to-door or mail-in surveys. All health care data are normalized into common formats and organized into a community health care report card listing values for each important community indicator.

Each indicator value is then compared against the state average, a peer group of communities' average, and other interesting values (e.g., a national goal for that indicator). The results of these comparisons are organized into an n-dimensional matrix based on favourable or unfavourable comparisons against each comparison dimension. Figure 1 shows a 2-dimensional comparison matrix based on state averages and peer averages. Community indicators that demonstrate unfavourable comparisons on all dimensions are highlighted as community health challenges. This set of health challenges are prioritized by passing each indicator through a set of ranking filters:

- Number Affected – Number of persons in the community affected by the indicator.
- Economic Impact – An estimate of the direct cost per case for individuals affected by the indicator.
- Availability of Efficacious Intervention – An estimate of the relative degree to which treatment or prevention is likely to be effective.

- Magnitude of Difference – The degree to which the community indicator is worse than the dimensional comparisons.
- Trend Analysis – For a five-year period is the trend favourable or unfavourable and what is the magnitude of change in the trend direction?

The community stakeholders are given an opportunity to weight the importance of each of the above filters. The final product of the CATCH methodology is a comprehensive, prioritized listing of community health care challenges. A more detailed description of the CATCH methodology with a complete listing of health care indicators can be found in [Studnicki et al. 97].

3 CATCH Data Warehouse

3.1 Limitations of Manual CATCH

While the value of CATCH is incontrovertible, the ultimate deployment of CATCH throughout Florida and the nation has been constrained by serious limitations.

- The hand crafted process is labour-intensive and slow. Hundreds of individual sources of data must be identified, a variety of formats reconciled, and data quality checked by hand. With current methods, it takes 3 to 4 months to complete a CATCH report for a single county.
- Longitudinal trend analyses over many years are cost prohibitive for most communities since each application is expensive and time-consuming.
- Most public health funding comes from state and federal governments. A statewide CATCH assessment would help to prioritize funding and serve to enable effective program evaluation based on quantifiable outcomes assessment. However, an automated methodology is critical for widespread adoption.

3.2 CATCH Data Warehouse Challenges

A CATCH data warehouse has been constructed to overcome these limitations, enabling both cost-effective report generation and ad-hoc analyses of critical health care issues. The construction of a data warehouse for public health care data poses major challenges beyond that required for the construction of a commercial data warehouse (e.g., retail sales).

- Data come from a diverse set of sources. Health care data are published in a wide variety of formats with differing semantics and there are few standards in the health care field for data.
- CATCH reports are disseminated to a diverse and geographically distributed set of stakeholders.
- The data warehouse is required to support the activities of public policy formulation. The sociopolitical issues of health care policy impact design features such as security, availability, data quality, and performance.

3.3 Data Warehouse Design

Important missions of a data warehouse include the support of decision-making activities and the creation of an infrastructure for ad-hoc exploration of very large collections of data. Decision makers should be able to pursue many of their investigations using browsing tools, without relying on database programmers to construct queries. The emphasis on end-user data access places a premium on an understandable database design that provides an intuitive basis for navigating through the data. The star schema or dimensional model has been recognized as an effective structure for organizing many data warehouse components [Gray/Watson 98]. The star schema is characterized by a centre fact table, which contains numeric information that can be used in summary reports. Radiating from the fact table are dimension tables that provide a rich query environment. This structure provides a logical data cube, with dimensions such as time and location identifying a set of numeric measurements within the cube.

The most appropriate facts are *additive* numeric data items that can be summed, averaged, or combined in other ways to form summary statistics. The only way to "compress" the millions of transaction items is to present some mathematical summarization. No human will want thousands, let alone millions, of items in answer to their queries. As Kimball points out, "The best and most useful facts are *numeric*, *continuously valued*, and *additive*" [Kimball 96].

The mission of the CATCH data warehouse is to support the automated and cost-effective application of the CATCH methodology, as well as to enable more detailed analyses that were not possible using the coarse-grained data that typified past CATCH reports. In order to meet these goals, the data warehouse design includes several levels of data granularity, from the coarse-grained data used in generic report production to actual event-level data, such as hospital discharges. The data warehouse includes major components at three levels of granularity, as illustrated by the data access pyramid in Figure 2.

1. Reporting tables with highly aggregated data are used to support the core CATCH reports, including comparisons between the target county and peer counties. These tables also provide fast response for interactive access via data browsing tools and can provide the foundation for simple community-wide Internet access.
2. There are families of star schemas that provide true dimensional data warehouse capabilities, such as interactive roll-up and drill-down operations. These components have care-

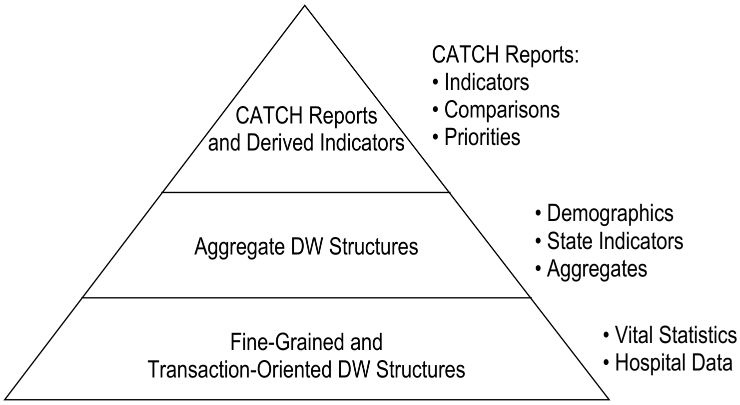


Fig. 2: The Data Access Pyramid

fully designed dimensions that can be utilized by more sophisticated data browsing tools. The star schemas are populated using thorough data staging and quality procedures that usually involve processing detailed data sets extracted by various health care agencies and organizations. Typically, the data is aggregated and transformed for loading into a family of related star schemas that share important dimensions and support interactive online analytic processing (OLAP) techniques.

3. For certain types of information, the design calls for retaining very fine-grained or even event-level data. An example is the hospital discharge data that includes each hospital discharge event for the more than 200 hospitals that are mandated to report such information in Florida. This data is retained at the transaction level because of the rich set of facts and dimensions available for analysis and the density of potential aggregations that result in negligible space savings.

These three levels of aggregation within the data warehouse combine to meet a wide range of reporting requirements and performance goals. Thus providing a flexible basis for disseminating health care information to community decision-makers.

ing the results in tabular or graphical form. Though online analytic processing (OLAP) usually incorporates roll-up/drill-down features, the navigation style is highly interactive and driven by previous steps in data exploration.

Summarization tasks are algorithmic in nature, applying techniques that summarize patterns in the data and usually produce models, often with some notion of reliability, which can be used to predict as well as describe the underlying data. Traditional statistics and data mining techniques are often used as summarization tools. A distinction is drawn between their uses as *exploratory* or *confirmatory* methods, but the results are a model or set of abstract patterns that can be applied to other data sets. For example, connectivity to statistical packages is an important interface component that allows analysts to use statistical techniques to confirm or more fully investigate interesting properties discovered through browsing in the CATCH data warehouse. While these techniques are clearly important and applicable to health care data warehousing, the following discussion focuses on the navigation tools and more traditional database access technologies being utilized in the project.

4 Modes of CATCH Data Dissemination

The human-computer interface is of paramount importance in the data warehouse environment and the primary determinant of success from the end-user perspective. In order to support analysis and reporting tasks, the data warehouse must have high quality data and make that data accessible through intuitive interface technologies. The act of releasing data in a warehouse is in a very real sense the same as publishing that data in printed form; retractions in both media can be very painful. Once the data becomes accessible, it may be included in reports, forecasts, and analyses that form the basis of decision-making activities within an organization or community. Therefore, data staging and quality procedures within the data warehouse are often among the most expensive and critical ingredients in providing a successful end-user experience.

The types of access in a data warehouse can be broadly categorized as either *navigation* or *summarization* tasks. Navigation activities include data browsing, ad-hoc queries, and traditional report generation. These tasks require human guidance and design to produce the appropriate queries, often present-

University of South Florida Health Sciences Center

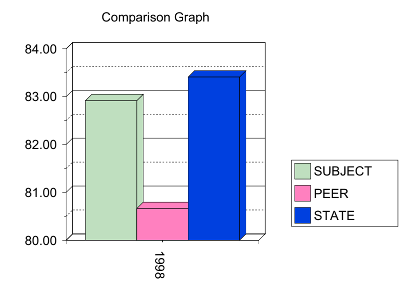
Indicator Fact Sheet

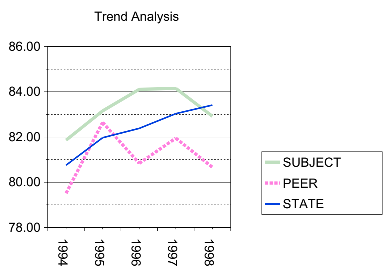
Indicator : First Trimester Prenatal Care - Total
County : Escambia
Indicator Category : Maternal and Child Health
Numerator Source: Florida Vital Statistics
Denominator Source: Florida Vital Statistics
Description : Births to all mothers who indicated they received prenatal care (PNC) during their first three months of pregnancy
Calculation: Total live births with first trimester prenatal care/total live births x 100

Peers
Alachua
Bay
Putnam

	Indicator Rate			Indicator Raw Values		
Current Year	Subject County	Peer Average	Florida	Subject County	Peer Average	Florida
1998	82.92	80.66	83.41	3,218	1,420	158,969

% of total live births



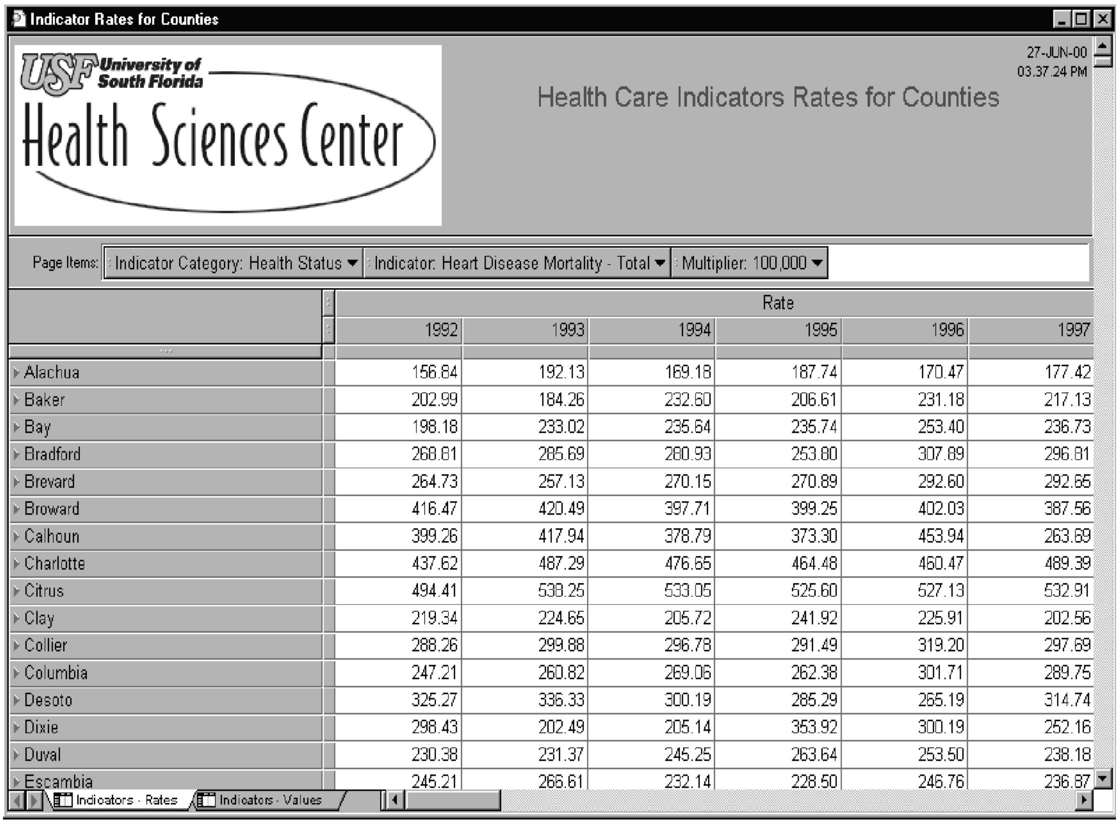


	Indicator Rate			Indicator Raw Values		
Year	Subject County	Peer Average	Florida	Subject County	Peer Average	Florida
1994	81.86	79.51	80.75	3,263	1,406	153,111
1995	83.15	82.65	81.97	3,184	1,483	154,325
1996	84.11	80.84	82.38	3,239	1,441	155,747
1997	84.15	81.95	83.03	3,340	1,471	159,175
1998	82.92	80.66	83.41	3,218	1,420	158,969

% of total live births

Healthy People 2010 : 90% receive care in 1st trimester

Fig. 3: An Example Indicator Fact Sheet



	Rate					
	1992	1993	1994	1995	1996	1997
Alachua	156.84	192.13	169.18	187.74	170.47	177.42
Baker	202.99	184.26	232.60	206.61	231.18	217.13
Bay	198.18	233.02	235.64	235.74	253.40	236.73
Bradford	268.81	285.69	280.93	253.80	307.89	296.81
Brevard	264.73	257.13	270.15	270.89	292.60	292.65
Broward	416.47	420.49	397.71	399.25	402.03	387.56
Calhoun	399.26	417.94	378.79	373.30	453.94	263.69
Charlotte	437.62	487.29	476.65	464.48	460.47	489.39
Citrus	494.41	538.25	533.05	525.60	527.13	532.91
Clay	219.34	224.65	205.72	241.92	225.91	202.56
Collier	288.26	299.88	296.78	291.49	319.20	297.69
Columbia	247.21	260.82	269.06	262.38	301.71	289.75
Desoto	325.27	336.33	300.19	285.29	265.19	314.74
Dixie	298.43	202.49	205.14	353.92	300.19	252.16
Duval	230.38	231.37	245.25	263.64	253.50	238.18
Escambia	245.21	266.61	232.14	228.50	246.76	236.87

Fig. 4: A Browsing Interface for County Level Indicators

4.1 Reports and Derived Indicators

The data warehouse components at the top of the pyramid provide the high-level reporting capabilities that were the focus of the original hand crafted assessments. The CATCH methodology has been refined through extensive field experience and provided a strong guiding framework for the initial data warehouse design. These top-level components include hundreds of indicators that are derived from the fine-grained data at the base of the pyramid. The identification of relevant indicators, describing the required calculations from underlying data, and understanding the use of information in the field are all valuable assets that have accrued through experience. This experience has been captured in many ways. The layout of the reports, OLAP interfaces, and the written analyses have all been refined over time. Most importantly, the hundreds of calculations necessary to derive the high-level indicators are implemented as stored procedures in the data warehouse and can be easily applied to new data or combined for novel approaches.

The derived indicators are used in the comprehensive community health assessment reports. Reports allow quick and easy access to comprehensive summaries and more detailed collections of information from the data warehouse. Figure 3 shows a fact sheet for one health indicator, with hundreds of such sheets being generated for each report. This type of predefined and thorough reporting is critical for implementing a more automated CATCH methodology. For example, the comparisons of target counties to peer counties and to the state are fundamental components of the original CATCH reports and important tools for community health care planners. The CATCH methodology has traditionally been centred on a large hardcopy report; so much of this content can be re-created in Web-friendly form and easily disseminated to local health planners. The advantage in this approach is the continued role of a strong methodology, rather than simply distributing raw data with no guidance in how to apply analytic methods.

4.2 Data Browsing and Aggregate Structures

Data warehouse browsing tools provide star query-like access through a flexible menu-based interface, with pull-down menus representing important data dimensions. These types of tools are easy to use and support ad-hoc exploration, but are usually controlled through some sort of administrative layer that determines the data available to end-users. In developing a flexible interface, there is a tradeoff between the ability to express ad-hoc queries and the ease-of-use that results from pre-defined constructs implemented by data warehouse designers and administrators. In addition, most of these tools are Web-enabled, providing dynamic access to a wide community through the Internet.

As noted in the data warehouse design discussion, the CATCH data warehouse consists of several levels of granularity from transaction-oriented data, such as hospital discharges, to summary data at the CATCH report level. Browsing tools can be used at all levels of the pyramid, but interface requirements will differ for each of the major components. For instance, the browsing tools provide a convenient method for CATCH analysts to view the preliminary report results with more detailed information than most community planners would want to sift through. Figure 4 shows an indicator over time for selected counties. Final report components may be generated using browsing tools, or more likely be implemented as part of a reporting function that more fully automates the process as discussed above.

A second and in some ways more important role for the browsing tools is to provide a flexible interface for more customized analysis. Aggregate data warehouse structures can often be used to improve browsing performance by physically instantiating the results of common roll-up operations. Custom analysis may also require additional calculations and aggregate structures are often an ideal location for such supplemental information. Example issues that are being investigated in this manner include racial disparities in infant mortality and the impact of surgical volumes on quality of care.

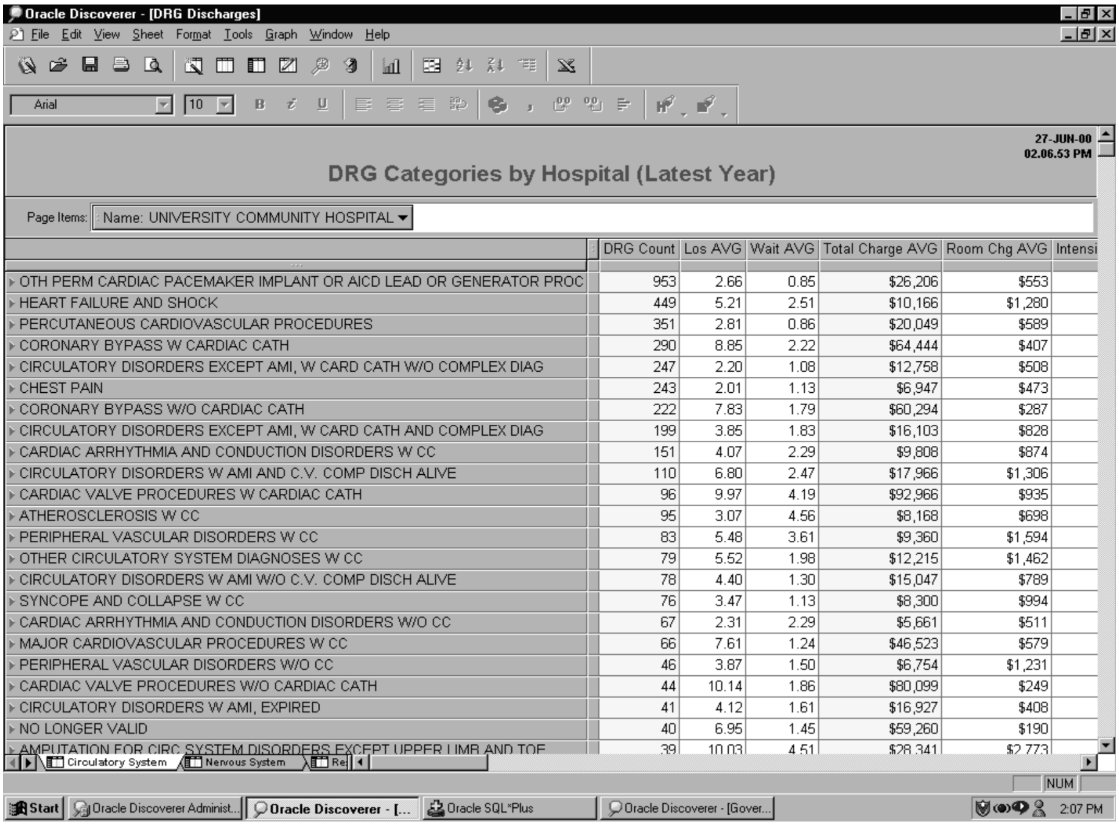
4.3 Fine-Grained Data Warehouse Structures

Health care issues highlighted by the CATCH methodology can be investigated more fully using the finer levels of detail maintained in the data warehouse. These tasks often entail querying the true dimensional star schemas that include age, gender, race, and other dimensions, or even the event-oriented data, such as hospital discharges. Thus the data warehouse allows the user to focus on issues such as differences in age or race with regard to specific health status indicators. Once decision-makers review the CATCH report, they may have specific issues that relate to the diverse communities that inevitably fall outside of arbitrary political boundaries. Figure 5 illustrates a detailed browsing screen in which volume, length of stay, and cost data are presented for a specific hospital by disease categories using diagnostic related groups (DRGs). It is clear how a hospital could effectively use this data for in-depth analyses of utilization and management decision-making.

5 Community Decision Making with CATCH Data

The CATCH data warehouse will result in widespread distribution of data previously unavailable to most communities as well as on-line access for specialized inquiry. This paper has focused on the rich variety of dissemination strategies available for making health care data available to local communities. Once received, however, many issues arise as to how the communities will make most effective use of the CATCH data for health care decision-making. This is an area with considerable research potential.

There is a rich literature on the decision-making process both with and without information technology. The study of group decision support systems and environments has a strong tradition in the management information systems field [Dennis 96]. In many ways, this important body of work is appropriate to health care decision-making that is usually group oriented. For example, the research in [Dennis et al. 98] studies the effects of minority influence on decision-making and finds that the presence or absence of technology has very different effects.



	DRG Count	Los AVG	Wait AVG	Total Charge AVG	Room Chg AVG	Intensi
OTH PERM CARDIAC PACEMAKER IMPLANT OR AICD LEAD OR GENERATOR PROC	953	2.66	0.85	$26,206	$553	
HEART FAILURE AND SHOCK	449	5.21	2.51	$10,166	$1,280	
PERCUTANEOUS CARDIOVASCULAR PROCEDURES	351	2.81	0.86	$20,049	$589	
CORONARY BYPASS W CARDIAC CATH	290	8.85	2.22	$64,444	$407	
CIRCULATORY DISORDERS EXCEPT AMI, W CARD CATH W/O COMPLEX DIAG	247	2.20	1.08	$12,758	$508	
CHEST PAIN	243	2.01	1.13	$6,947	$473	
CORONARY BYPASS W/O CARDIAC CATH	222	7.83	1.79	$60,294	$287	
CIRCULATORY DISORDERS EXCEPT AMI, W CARD CATH AND COMPLEX DIAG	199	3.85	1.83	$16,103	$828	
CARDIAC ARRHYTHMIA AND CONDUCTION DISORDERS W CC	151	4.07	2.29	$9,808	$874	
CIRCULATORY DISORDERS W AMI AND C.V. COMP DISCH ALIVE	110	6.80	2.47	$17,966	$1,306	
CARDIAC VALVE PROCEDURES W CARDIAC CATH	96	9.97	4.19	$92,966	$935	
ATHEROSCLEROSIS W CC	95	3.07	4.56	$8,168	$698	
PERIPHERAL VASCULAR DISORDERS W CC	83	5.48	3.61	$9,360	$1,594	
OTHER CIRCULATORY SYSTEM DIAGNOSES W CC	79	5.52	1.98	$12,215	$1,462	
CIRCULATORY DISORDERS W AMI W/O C.V. COMP DISCH ALIVE	78	4.40	1.30	$15,047	$789	
SYNCOPE AND COLLAPSE W CC	76	3.47	1.13	$8,300	$994	
CARDIAC ARRHYTHMIA AND CONDUCTION DISORDERS W/O CC	67	2.31	2.29	$5,661	$511	
MAJOR CARDIOVASCULAR PROCEDURES W CC	66	7.61	1.24	$46,523	$579	
PERIPHERAL VASCULAR DISORDERS W/O CC	46	3.87	1.50	$6,754	$1,231	
CARDIAC VALVE PROCEDURES W/O CARDIAC CATH	44	10.14	1.86	$80,099	$249	
CIRCULATORY DISORDERS W AMI, EXPIRED	41	4.12	1.61	$16,927	$408	
NO LONGER VALID	40	6.95	1.45	$59,260	$190	
AMPUTATION FOR CIRC SYSTEM DISORDERS EXCEPT UPPER LIMB AND TOE	39	10.03	4.51	$28,341	$2,773	

Fig. 5: A Browsing Interface for Hospital Information

Another important contributing area would be the political process and its ramifications to decision-making [Mintzberg 73]. Certainly, policy making in health care is very much a political process.

The use of the CATCH methodology and state-of-the-art data warehousing technology across many Florida communities will provide a rich research opportunity for studying many interesting issues on group decision-making in community health care organizations. Some of the issues we plan to study include the presence of a champion, group composition, socio-political context, and the ease of access and usefulness of the data. The complexities of each issue and the interrelationships among these issues make the design of research studies both a challenge and an opportunity.

Acknowledgments

The Florida Dept. of Health is a research partner. Research collaborators in the CATCH project include E. Gilbert, R. Marsh, D. McCorkel, B. Myers, M. Nevrekar, M. Pearl, J. Slayton, B. Steverson, and S. Hedge-Desai.

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