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Jana Zvárová Memorial Conference 2018 in Prague

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The volume at hand is dedicated to acknowledging and honoring our unforgettable friend and colleague Prof. Jana Zvárová, founder and Editor in Chief of both this European Journal for Biomedical Informatics and the International Journal on Biomedicine and Healthcare, who suddenly and unexpectedly passed away in July 2017. Prof. Zvárová was an extraordinary personality, who influenced the development and improvement of health and social care by means of medical informatics, biomathematics and biostatistics as well as epidemiology both nationally and globally. She dedicated her excellent work based on a broad education and huge practical experience to the benefit of patients and health professionals, but first of all to teaching undergraduate, PhD and PostDoc students from the Czech Republic as well as other countries, acknowledging the importance of educating and training current and future staff for best serving the community. Due to this engagement Jana Zvárová received a big number of awards, fellowships, medals, etc. during her professional life that lasted until her last breath.

Frequently in cooperation with the Editors, authors and other colleagues, Jana Zvárová has organized quite a number of conferences and educational events covering such diverse topics as biomathematics, biostatistics, medical informatics, eHealth, mobile health, medical documentation, EHR systems, clinical decision support, interoperability challenges and related standards, but also clinical, social and legal aspects. At EuroMISE and also later at the Center for Biomedical Informatics at Charles University Prague (launched in 2006, based on an agreement between the Charles University Prague and the Czech Academy of Sciences) lecture series on advanced eHealth, knowledge representation and management, medical and clinical guidelines, ontologies, EHR systems and interoperability were organized by Jana. With the establishment of the EuroMISE Mentor Association (EMA) in 2013, mentoring courses addressing regular and PhD students were organized in cooperation and coordination with, and on the topic of, some of those international conferences organized in Prague. Jana Zvárová specifically supported the series of International HL7 Interoperability Conferences (IHIC) by giving them a publication platform at the European Journal for Biomedical Informatics.

Topics from some of the fields Jana was interested in will be covered in this Special Issue of the European Journal for Biomedical Informatics. Most of the papers in this issue will be presented during the Jana Zvarova Memorial Conference, 4 May 2018 in Prague.

This volume starts with an obituary for Jana Zvárová. George Mihalas, Vice-Chair of the History Working Group of the International Medical Informatics Association (IMIA) acknowledges and honors her professional life and achievements. Further contributions in this volume specifically address in more or less detail cooperation with Jana Zvárová in the context of electronic healthcare documentation, EHR systems, interoperability, knowledge management and decision support, educational challenges, but also the role of women in the domain of health informatics. Bernd Blobel discusses requirements, standards and solutions for interoperable EHR systems with some focus on user perspectives, thereby also referring to earlier papers with a more technical focus. Elske Ammenwerth addresses the transformation of the patient into a responsible care manager by assessing the role of patient portals for empowering them. The analysis emphasizes the situation in Austria, but also considers the aspects in general. Jan Kalina discusses the challenges of Big Data analysis in medicine. He illustrates the complexity reduction of high-dimensional data with practical research problems such as face recognition and gene analysis. František Och presents the project "Comprehensive assessment of the clinical effect of specifically selected natural remedies on the treatment of knee osteoarthritis" Jana Zvárová was strongly involved in. In that context he presents the interdisciplinary challenge of evidence-based medicine in balneology as initiated by Jana. Lenka Lhotska discusses the evolution of decision

support systems in healthcare, specifically highlighting the role of distributed systems and the Internet of Things (IoT). Izet Masic focuses on the field Jana Zvárová was especially engaged in: education in medical informatics, biostatistics and related domains and applications. He specifically highlights the situation in his home country Bosnia-Herzegovina under the perspective of the Bologna Process. Pirkko Nykänen summarizes the investigations on the specific role and achievements of women in health informatics. Diane Whitehouse finally reports about conversations with Prof. Jana Zvárová on contemporary developments in digital health

In the addendum of this Jana Zvárová Special Issue of the European Journal for Biomedical Informatics, we re-publish the official obituary of IMIA and EFMI concerning Jana Zvárová, which appeared first in the IMIA Newsletter 82 from July 2017.

The Guest Editors of this EJBI volume are indebted to thank all authors for their excellent work in memorizing Jana Zvárová. They wish all interested parties an enjoyable reading.

Jana Zvárová – A Distinguished Personality of Medical Informatics

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1 Introduction

The history of science has shown that the development of any field is the result of many researchers' efforts, some of whom put a specific footprint on certain important aspects in some stages of the field's development. When we think of Jana Zvárová, we have first to reveal her efforts in promoting the field of medical informatics, while this field was still seeking its proper definition, and mainly to underline her role in favouring and supporting direct contacts and collaborations between the scientists, in the political context of a Europe still politically divided into "East and West" [1].

This biographical paper tries not only to recall Jana Zvárová's sustained scientific activity but also intended to evoke her remarkable personality.

2 Early Work: Studies and Scientific Pursuits

Jana Zvárová was born in 1943 in Prague, Czechoslovakia. She received her degree in mathematics, graduating the Faculty of Mathematics and Physics of the Charles University in Prague. Working after graduation with the Faculty of Paediatrics, she took contact with the complexity of medical data, deciding to approach the interdisciplinary area at the intersection of mathematics and biomedical sciences. She started her PhD studies in 1967 under the supervision of Prof. Dr. Albert Perez, member of IFIP, who brought her attention to the field of medical informatics and opened the contacts with founders of IMIA [2]. A unique chance to continue her PhD studies at Medical Faculty of the University of Edinburgh gave her an integrative vision upon the great potential of medical data analysis and new knowledge on practice of medical computing. She realized that medical applications of statistical methods will be among the first applications of computers in medical research, initiating in 1978 the medical informatics section within the Czech Society of Biomedical Engineering, one of the societies of the Czech Association of Medical Societies of J.E.Purkyně.

In 1983, in the light of a slight political relaxation, with the support of Jan Roukens, Jana Zvárová managed to attend MEDINFO 83 in Amsterdam, IMIA's tri-annual World Conference on Medical Informatics, foreseeing the importance of direct communication between scientists and the true role of scientific meetings for establishing durable collaborations. Thus, she participated in the 6th COMPSTAT Conference [3], organized in 1984 in Prague by International Association for Statistical Computing – IASC [4] for the first time in Eastern Europe.

Previous contacts and favourable circumstances of the period allowed for the organization of a working conference in Prague in1985 under the auspices of International Medical Informatics Association (IMIA, a special interest group of the International Federation for Information Processing (IFIP), to which Jana Zvárová paid her due attention.The topic of the conference – computer-aided medical decision - remained her beloved subject throughout her life. She requested François Grémy and Jan van Bemmel to chair this four-day meeting. An important book from North-Holland Publishing Company was the result of this conference, the first one of that kind in the communist world [5, 6]. This conference played an important role in the history of European medical informatics, as nicely described by van Bemmel, Ball &Hasman: "*Since that time, Jana organized many meetings and projects herself, in close collaboration with several colleagues from abroad. During the past years, we have learned to know many active members in IMIA and EFMI; all of them were active and energetic, but hardly any of them could be compared with Jana Zvárová, whose creativity and endeavours were far beyond those of all others*" [6].

Despite all difficulties, specific for East European countries before the collapse of communism in 1989, Jana Zvárová worked hard for pursuing her scientific goals, coordinating research projects or organizing and attending local or international conferences. She paid a special attention to educational issues [7], a preoccupation which she continued for more decades.

As a result of her proposal, the Czech Society of Biomedical Engineering and Medical Informatics joined both the European Federation for Medical Informatics (EFMI) [8] and the International Medical Informatics Association (IMIA) [9], having Jana Zvárová as representative in both organizations.

3 Ascension Period

The years after the "velvet revolution" in 1989 in Czechoslovakia offered better conditions for plenary assertion of work potential and scientific career of Jana Zvárová: she received her State Doctorate Charles University in 1991 and the position of full professor, the title being handed to her by the then president Václav Havel; in the same year she also obtained the highest Czech title of Doctor in Sciences of the Academy of Sciences of Czech Republic [2, 6].

An important achievement of Jana Zvárová came from the European project "Education in the Methodology Field of Healthcare" – the creation in 1994 of the EuroMISE Centre for Education in Medical Informatics, Statistics and Epidemiology, of Charles University and Czech Academy of Medical Sciences. EuroMISE aimed to offer educational programs in a broad European co-operation focusing on teaching teachers and health professionals from Central and Eastern European countries [10, 11]. The activities of this centre received a strong support from EFMI members and also other outstanding professors and scientists: Jan H. van Bemmel, Arie Hasman, Rolf Engelbrecht, Reinhold Haux, Bernard Richards, Hartmut Dickhaus, Bernd Blobel, etc. It was functional several years even after the official end of the project; more than 150 participants have attended these courses [12, 13].

Three other European projects have synergistically completed her scientific activities: MUM, TripleC and MGT.

MUM (Managing Uncertainty in Medicine, 1994 – 1996) aspired to incorporate logical approaches probability methods into diagnostic knowledge-based systems and to gain practical experience in the field of medical data analysis and knowledge processing by introducing software tools in selected medical health care facilities.

TripleC was a continuation of I4C project (Integration and Communication for the Continuity of Cardiac Care 1998-2000). The scope was to develop methods for designing the ORCA (Open Record for Care) Electronic Health Record (EHR) applied to cardiology. First structured EHR in Czech and Slovak languages were created allowing systems interoperability. The results of this project were further developed in the EuroMISE Centre. A Minimum Data Model of a Cardiology Patient was also proposed, along with a voice-recognition component of an EHR used in dental medicine - DentCross.

The objective of MGT (Medical Guideline Technology, 1998-2000) was to develop computerized tools providing patient-specific practice guidelines; three main applications were created in the domain of hypertension and cardiology by countries that differed in their health care systems. Results were validated in co-operation with the Municipal Hospital in Čáslav.

4 Full Affirmation Period

The intense activity involved in these projects and the numerous co-payments that have taken place within them have elevated Jana Zvárová among the most dynamic and well-known researchers in medical informatics, both nationally and internationally.

Together with Štěpán Svačina they set up the Scientific Board of Biomedical Informatics, chaired by Jana Zvárová, as a result of cooperation agreement between Charles University and the Czech Academy of Sciences. This action has been followed by the foundation of the Centre for Biomedical Informatics (CBI) in 2006. Under the directorship of Jana Zvárová CBI gathered about eighty personnel, highly qualified, forming a strong multidisciplinary team. As a national research centre and joint work environment, CBI aimed to coordinate advanced studies in genetic aid for the diagnosis and prognosis of cardiovascular diseases as well as decision support systems for personalized healthcare with applications in cardiology and dental care. It also contributed to the enhancement of the quality of PhD programs in biomedical informatics. Unfortunately, despite the very good results, CBI's activities have been terminated in 2011 due to some bureaucratic reasons.

An important part of her work was represented by publication activities which comprise 10 monographs, 3 patents and over 300 articles in peer-reviewed journals, cumulating over 600 citations [2]. An appreciated outcome in this direction was the publication of the European Journal of Biomedical Informatics, EJBI [14], whose Editor in Chief she was since 2005, and which is one of the EFMI endorsed journals. By that time the evolution of technologies and strategies concerning publication activities became the object of an EFMI Task Force in which Jana Zvárová played an important role [15].

She delivered several invited lectures at national and international meetings, acting in scientific program committees and conducting significant peer reviewing for conferences and journals, serving also in the board or editorial committees of different professional journals. For her expertise she also was asked several times by the European Commission and Czech governmental institutions in project evaluation activities [2].

Her rich experience has been revealed once again at the unforgettable EFMI Special Topic Conference " Data and Knowledge for Medical Decision Support", organized by her in Prague in the spring of 2013. The program comprised

a synergic mix of her beloved previous topics, approached in a modern manner, strengthened also by prestigious outstanding keynote speakers – Jan van Bemmel and Marion Ball [16]. The large audience attended with interest also the panel on History of European Medical Informatics [17], an avant-premiere event to mark four decades of EFMI activities.

She has never relinquished the idea that the education of new generations of specialists should be an important task of all scientists, continuing to develop the methodologies for education and training in medical informatics [18]. In the same direction is her initiative to edit an accessible journal (both in English and Czech language) – International Journal on Biomedicine and Healthcare, published since 2013 and having Jana Zvárová as Editor in Chief [19].

Likewise, for facilitating a more intensive cooperation among teachers and researches in the field of medical informatics, the EuroMISE Mentor Association was founded in 2014, focusing mainly on mentoring activities in the field of biomedical informatics and biomedical informatics research. EuroMISE Mentor Association, EMA, is closely cooperating with Czech Society of Biomedical Engineering and Medical Informatics.

5 Recognition of the Professional Prestige of Jana Zvárová

Jana Zvárová was a modest person, never hunting titles, prizes or positions. Nevertheless, her professional competence was unanimously recognized, both in her country and abroad. She was a member of the Board of the Czech Society for Biomedical Engineering and Medical Informatics for a long period of time, head of the Biomedical Informatics Section of the Society, member of the group for electronic healthcare of Czech Medical Association J.E. Purkyně , member of Czech Society for Cybernetics and Informatics and member of Czech Statistical Society.

Jana Zvárová's scientific reputation was awarded by several distinctions and honorary titles [2]: Honorary Membership of Romanian Society of Medical Informatics (1997), Medal of Erasmus University Rotterdam Department of Medical Informatics (1998), Honorary Membership in the Foundation Grigore C. Moisil for Applied Informatics (1999), University medal of University for Health Informatics and Technology Tyrol (2004), Honorary Membership in the Czech Society of Biomedical Engineering and Medical Informatics (2004), Medal of Charles University, Faculty of Science (2005), Medal of Charles University 1st Faculty of Medicine (2008), Honorary Membership in the Society for Cybernetics and Informatics (2010).

A special attention was paid by Jana Zvárová to her role within EFMI and IMIA, showing a deep feeling of her responsibilities as a national representative. She not only participated in almost all the conferences organized by EFMI and IMIA but has always supported the participation of her co-nationals, especially her young collaborators, initiating them in international cooperation. Her position in EFMI Council Meetings or IMIA General Assemblies was always well balanced and realistic, gaining the support of the whole audience. In 2015, as a recognition of her professional merits and excellent activities, she was awarded the honorary title of "EFMI Fellow" [8] and in 2017 she was elected as member of International Academy of Health Informatics Sciences (IAHSI).

6 Personality of Jana Zvárová

The enumeration of achievements, papers, projects, titles or honours would remain a simple list of facts unless revealing the remarkable personality of Jana Zvárová and also understanding the tempestuous socio-political context of the period in which she worked. The friendly atmosphere in EFMI let us know better one another, understand, support and help whenever possible. That is why in this section she will be simply referred "Jana".

Jana was a tenacious person, following patiently her scientific goals. With a solid mathematical background, her first contact with the complexity of medical data opened her desire to deepen the data processing field applied in biomedicine and healthcare, a direction which she perseveringly followed all her life. Her scientific goal was "*to try to use methods from mathematical statistics and information theory to solve medical problems, e.g. in cardiology, gynaecology, obstetrics, rheumatology, dentistry, epidemiology and public health*" [20].She had the chance to be initiated in information theory by Albert Perez, then to go for PhD studies to Edinburgh where she not only learned many new approaches and ideas on medical data analysis and computing, but also enjoined having fruitful discussions with her colleagues. Unfortunately, due to the political changes in Czechoslovakia in 1968 she had to interrupt her PhD stage and return back home. Starting to work at the Institute of Haematology and Blood Transfusion she joined a group of young researchers in biocybernetics; they became more aware about the increasing role of computers in medical information processing, particularly in medical decision making. But, due to the contacts with IFIP-TC4, this group was going to receive another blow, being perceived as unacceptable for political leaders at this time for their open minded opinions and was dissolved in 1976 [20].

Jana always struggled for a good and close collaboration between the scientists [12, 13]. The experiences she had at the beginning of her scientific career have led her to decide to fight against any type of discrimination or isolation. And, when the opportunities have occurred, she put these ideas in practice. Having a strong support from Jan van Bemmel, François Grémy and other IMIA leaders, she organized a series of conferences in Prague, starting with the memorable conference in 1985 [5]. This conference was a real success, representing a milestone in European medical informatics.

Indeed, the strategic position of Prague, in Central Europe, easily accessible from Western Europe countries, but within the Eastern block, allowed in some cases also participation of people from communist countries. She continued to follow this credo also after the big political changes in Eastern Europe in 1989. Thus, the most successful of her projects – EuroMISE – became a flagship of cooperative actions in Europe since 1994, followed recently by EMA – EuroMISE Mentor Association, oriented also towards a closer cooperation among teachers and researches in the field of medical informatics.

Jana was a school creator, raising educational activities at highest levels [7, 10, 18]. Since joining Charles University, she has given great importance to educational tasks. She was confident that the scientific progress cannot be imagined without preparing new generations of highly skilled professionals. The creation of EuroMISE as well as the organization of several seminars, workshops and conferences fits this view. She was always surrounded by several young collaborators when attending international conferences.

Shortly before her death she planned to publish a special issue on Women in Health Informatics in the International Journal on Biomedicine and Healthcare, co-edited together with Pirkko Nykanen and Dianne Whitehouse [19, 21]. This issue appeared in December 2017, and many of the international medical informatics female professionals were invited by her to make a contribution.

She was a conscientious and modest person, honest, perseverant, always ready to engage in voluntary activities within EFMI and IMIA, with good spirit of initiative, skilful leader, excellent organizer, respected by her colleagues for her competence and her outstanding merits. More details about her scientific work are available on professional websites [22].

Finally, as described by van Bemmel, Ball & Hasman [6]: *"Not only was Jana a professional of the first order, she also was a devoted wife and mother having raised very successful children and being a role model for women in the field of Health Informatics internationally"*.

Her passing away shocked the entire medical informatics community, her activity and personality being evoked by several colleagues and friends [2, 6, 8, 9, 21].

Through her work, her life and her example, Jana Zvárová has earned a well-deserved place in the world pantheon of medical informatics. We will always remember her!

7 Photo Gallery

Figure 1. Jana Zvárová

Figure 2. Shigekotu Kaihara, Jana Zvárová, François Grémy and Jan H. van Bemmel.

Figure 3. Albert Perez, Jan H. van Bemmel, Jana Zvárová, Leodegar Cigánek and Jan Münz members of the committees of the first IMIA conference in Prague 1985.

Figure 4. Diane Whitehouse, Izet Masic, Arie Hasman, Casimir Kulikowski, Jana Zvarova, George Mihalas (chair), Marion Ball and Jan van Bemmel in Prague, April 2013, as panelists about Medical informatics history (from left to right).

Figure 5. Invited speakers at IJM EuroMISE: Arie Hasman, Jana Zvarova, Rolf Engelbrecht, Pirkko Nykanen, William Edward Hammond, Lenka Lhotska, Bernd Blobel and Izet Masic (from left to right).

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Interoperable EHR Systems – Challenges, Standards and Solutions

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Abstract

Background: Electronic Health Record Systems (EHRS) and Personal Health Record Systems (PHRS) are core components of infrastructure needed to run any health system. Objectives: As health systems undergo paradigm changes, EHRS and PHRS have to advance as well to meet the related interoperability challenges.

Methods: The paper discusses EHR types, implementations and standards, starting with different requirements specifications, systems and systems architectures, standards and solutions.

Results: Existing standards and specifications are compared with changing requirements, presenting weaknesses and defining the advancement of EHRS, architectures and related services, embedded in advanced infrastructure systems.

Conclusion: Future EHR systems are components in a layered architecture with open interfaces. The need of verifying data models at business domains level is specifically highlighted. Such approach is enabled by the ISO Interoperability Reference Architecture of a system-oriented, architecture-centric, ontology-based, policy- driven approach, meeting good modeling best practices.

Keywords

EHR systems; Architecture; Interoperability; Standards

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1 Introduction

The paper at hand is based on, and updates, publications reflecting activities on EHR systems, interoperability challenges and related standards, organized by, or jointly with, Jana Zvarova this Special Issue is dedicated to. That way, it acknowledges Jana Zvarova's engagement in the field. In this paper, her interdisciplinary focus and her priority given to both patients and health professionals are especially reflected.

Documentation and healthcare have been interrelated since the ancient times, thereby meeting the following functions: being a reminder for the carer, enabling communications between actors involved in care processes, serving as basis for education, acting as tool for developing the discipline. Later on, the legal perspective of documentation has been added. Besides observation, as well as performed or intended actions, documentation represents the context of the actors including knowledge, skills, experience, but also organizational and legal requirements. After Segen's Medical Dictionary, medical documentation consists of "operative notes, progress notes, physician orders, physician certification, physical therapy notes, emergency room records, or other notes and/or written documents; it may include ECG/EKG, tracings, images, X-rays, videotapes and other media" [1]. The terms medical chart, medical record or health record describe systematic documentation of a single patient's medical history [2], where the first two present an organization centric, and the third a cross-organizational perspective, thereby going beyond the original medical perspective by extending the considerations to social, environmental, prevention, lifestyle, and other implications. Electronic documentations add to those principles information and communication technologies (ICT) and related facilities.

Comprehensive and accurate information about the status and processes directly and indirectly related to the health of the subject of care must be provided and managed to enable safe, high quality, and efficient care services [3]. An early overview on the development levels of electronic healthcare records (EHCRs) has been provided by the US based Medical Record Institute [4] (Figure 1).

According to ISO/TR 20514 Health informatics – Electronic health record – Definition, scope and context [5], an EHR is defined as "a repository of information regarding the health status of a subject of care in computer processable form". It provides the "ability to share patient health information between authorized users of the EHR and the primary role of the EHR in supporting continuing, efficient and quality integrated health care". The same ISO specification defines an EHR system as "system for recording, retrieving and manipulating information in electronic health records", or – adapted from the Institute of Medicine's Computer-based Patient Record System definition [6] "a set of components that form the mechanism by which electronic health records are created, used, stored and retrieved including people, data, rules and procedures, processing and storage devices, and communication and support" facilities.

There are different types of EHR depending on the viewpoint applied. From a logical and organizational perspective, we can distinguish centralized and de-centralized or distributed EHR systems. Regarding its focus, we define organization-centric Electronic Health Records (EHRs) on the one hand and Personal Health Records (PHRs) beyond the regulated medical perspective on the other hand. From the management perspective, we distinguish the professionally/organizationally moderated EHR from a personally moderated EHR where the subject of care controls the use by deciding privilege management and access control rules. Both are legal records. Contrary to those EHRs, PHRs cannot count for legal records, as they allow the subject of care to enter or delete any information. Regarding the time dimension, an EHR can represent an episode (EHR extract) or a life-long record (EHR service). We can distinguish EHR approaches according to the access model used (indirect via regional or national switch points vs. direct access to central EHR systems) or according to the implementation technology such as integrated system, federated system, or service oriented system. Because of their rational roots and driving factors, all those approaches have their right to exist at least temporarily. Therefore, they exist also practically in co-existence or concurrency. The aforementioned approaches develop continuously, thereby showing some convergence. The consequences of those EHR types for the interoperability level possible will be discussed in some more detail in Section 3.

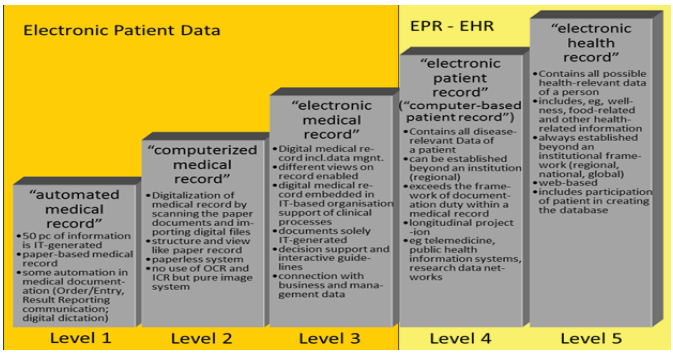

Figure 1. EHCR - Development Levels (Medical Record Institute, Newton, MA) [10].

2 EHR Systems' Objectives and Requirements

2.1 Health Systems Paradigm Changes EHR Specifications and Solution Have to Meet

For meeting the challenge to enhance quality and safety of patients' care as well as to improve efficiency and efficacy of care processes, changes regarding the organizational, methodological and technological paradigms for performing health service delivery are under way. Table 1 presents those changes at a high level.

EHR systems, enabled by corresponding architectural approaches, have to support those paradigm changes by undergoing the same transformation towards a highly complex, highly dynamic, multi-disciplinary/multi-domain advanced system in an intelligent, self-organizing way as the healthcare system does. Therefore, a systematic, formalized and adaptive approach is required to sharing and harmonizing ICT, domain, and personal ontologies, conditions and context at runtime.

For deploying EHR/PHR systems as core applications of health systems enabling cooperation for safe, high-quality and efficient care processes, certain content-related as well as functional requirements must be defined to be met by all involved systems. For that purpose, such requirements have been standardized or defined by institutions with sufficient authority. Examples of such requirements sets are the HL7/ISO standards EHR-S Functional Model and PHR-S Functional Model, but also the definitions of the Meaningful Use Program as well as the HIMSS Analytics Electronic Medical Record Adoption Model (EMRAM). The compliance of solutions with those requirements could be possibly certified to give vendors and providers, but also payers involved confidence in the adoption and maturity of those solutions. These requirements specifications are summarized below.

2.2 HL7 Electronic Health Record System Functional Model (HL7 EHR-S FM)

The HL7 EHR-Systems Functional Model (HL7 EHR-S FM) [7], also standardized at ISO as ISO/HL7 10781:2015 HL7 EHR-Systems Functional Model [8], provides a reference list of functions that may be present in an Electronic Health Record System (EHR-S) from a user perspective that allows managing and maintaining a health record for accomplishing various clinical, research and business purposes. Through the creation of Functional Profiles for care settings and realms, the EHR-S Functional Model enables a standardized description and common understanding of functions intended or available in a given healthcare setting (e.g. ambulatory care, behavioral health,

Table 1. Paradigm changes impacting the transformation of health service delivery.

Organizational	Methodological	Technological (Amount of Data)
• Organization-centric care • Process-controlled care (DMP) • Person-centric care	• General care addressing health problems (one solution fits all) ➢ Phenomenological Approach • Dedicated care (stratification of population for specific clinically relevant conditions) ➢ Evidence-Based Medicine • Personalized, preventive, predictive and participative care considering individual health state, conditions and contexts, OMICS data, etc. (stratification of population by risk profiles) ➢ Systems Medicine, from art to multi-disciplinary science, from elementary particle to society • Cognitive care → informed decision	• Mainframe (KB) • Client/Server (MB) • Internet (GB) • Distributed systems, mobile technologies, nano- and molecular technologies, knowledge representation & -management, Artificial Intelligence, Big Data & Business Analytics, Cloud Computing, Social Business, Cognitive Computing (PB, YB)

intensive care, and cardiology, office practice in one country or primary care in another country). The Infoway Project Canadian EHR Blueprint introduced later some details as an example of a jurisdictional profile. It lists function identifier, function names and a related statement (meaning), but also conformance criteria (shall, should, may) and relationship to other functions. The HL7 EHR-S FM, R1, outlines important features and functions that should be contained in an EHR system. The HL7 EHR-S FM, R2, builds on Release 1.1 of the model, offering a more comprehensive set of functions and criteria.

2.3 HL7 Personal Health Record System Functional Model (HL7 PHR-S FM)

The HL7 Personal Health Record System Functional Model, Release 1 standard [9] specifies a standardized description and common understanding of features and functions necessary to create and effectively manage PHRs that help an individual maintain a longitudinal view of his or her health history. Personal Health Record information is expected to be sent, received, or exchanged from multiple systems, including: Electronic Health Record systems, insurer systems, payer systems, health information exchanges, public health systems, Internet-based health education sites, clinical trials systems, and/or collaborative care systems.

2.4 ISO 18308 Requirements for an Electronic Health Record Architecture

ISO 18308 [10] defines the set of requirements for an EHR architecture. The requirements are formulated to ensure that EHR systems are faithful to the needs of healthcare delivery, are clinically valid and reliable, are ethically sound, meet prevailing legal requirements, support good clinical practice and facilitate data analysis for a multitude of purposes. ISO 18308:2011 does not specify the full set of requirements that need to be met by an EHR system for direct patient care or for other use cases, but the requirements defined by ISO 18308:2011 do contribute to the governance of EHR information within such systems.

2.5 Electronic Medical Record Adoption Model

The HIMSS Analytics Electronic Medical Record Adoption Model (EMRAM) [11] defines a methodology and algorithms to measure adoption and utilization of EMR functions, that way scoring the capabilities of EMR systems. The application of this model and the resulting assessment of EMR systems are not limited to the USA. Also hospitals in other countries around the world are assessed and get awarded the related EMRAM level [12]. EMRAM defines 8 levels of EMR adoption and maturity according to the inclusion of ancillary clinical systems such as pharmacy, laboratory, and radiology, PACS and non-DICOM image management, internal interoperability, security features, intelligent data management up to big data and analytics, cross-organizational interoperability and privacy. In some more details, the EMRAM levels are specified as follows:

- Level 0) No clinical ancillaries are installed.
- Level 1) The three basic ancillary clinical departmental systems (Laboratory IS, Pharmacy IS, Radiology/ Cardiology IS), but also the radiology/cardiology PACS and non-DICOM image management systems are installed.
- Level 2) A clinical data repository (CDR) enables full interoperability between the aforementioned units, supported by a controlled vocabulary and a clinical decision support (CDS) rule engine for rudimentary conflict checking; Furthermore, basic security services such as access control and usage management, encryption, mobile security, etc. are implemented.

- Level 3) Nursing and allied health documentation (NAHD) is partially (50%), in emergency departments fully, implemented in integrated in the CDR; Electronic medication administration record (eMAR) and role-based access control (RBAC) are installed.
- Level 4) Computerized practitioner order entry (CPOE) is partially (50%), in emergency departments fully, implemented, supported by a clinical decision support (CDS) rule engine for rudimentary conflict checking; NAHD has grown from 50 to 90%; Where publicly available, clinicians have access to national or regional databases and registries to support decision making; Nurses are supported by CDS capability related to evidence-based medicine protocols; Precautions for EMR downtime and network intrusion detection are implemented.
- Level 5) Full physician documentation with structured templates and discrete data is partially (50%), in emergency departments fully, implemented in the hospital; Nurse order/task completion can be tracked and reported; Intrusion detection is extended to intrusion prevention; Mobile security is implemented, including the opportunity to wipe remotely data from lost/stolen devices.
- Level 6) Comprehensive process management for administering medications, blood products, and human milk is partially (50%), in emergency departments fully, implemented; Integration of eMAR with CPOE, Pharmacy IS and Laboratory IS improves safe point-of-care processes and results; Process management is CDS supported; Mobile/portable device security is applied to user-owned devices, that way properly managing BYOD (bring your own device) policies.
- Level 7) Disbanding paper charts and integrating all data modalities completely in the EMR system by supporting all aforementioned capabilities including data governance, disaster recovery, security and privacy; Deployment of data warehousing to analyze clinical data patterns for improving care quality, patient safety, and care delivery efficiency; Health information exchange (HIE) across the healthcare ecosystem, using standardized health information exchange protocols such as CCD or FHIR resources [13]; Continuity of care is realized throughout the hospital.

2.6 Meaningful Use

The US Health Information Technology for Economic and Clinical Health (HITECH) Act as part of the American Recovery and Reinvestment Act was signed into law in 2009 to promote the adoption of electronic health records through meaningful use. For improving quality and efficiency of care delivery as well as enhancing coordination between providers, but also privacy and security of personal information and the engagement of patients in their own health through health information and health information exchange (HIE), the US Department for Health and Human Services (HHS) has established an EHR Incentive and Certification Program managed by the Centers for Medicare & Medicaid Services (CMS). It defines requirements and objectives for EHR systems of eligible providers, both professionals and hospitals, to benefit from that program.

The EHR Incentive Programs consist of three stages [14]:

- **Stage 1** set the foundation for the EHR Incentive Programs by establishing requirements for the electronic capture of clinical data, including providing patients with electronic copies of health information. In detail, the following functionalities are required: Implementation of drug-drug and drug-allergy interaction checks; maintaining problem, medication and medication allergy lists; recording of specific demographics, vital signs and children's smoking information; implementation of CDS rules; reporting quality measures; establishing basic security and privacy services.
- **Stage 2** expanded upon the Stage 1 criteria with a focus on advancing clinical processes and ensuring that the meaningful use of EHRs supports the aims and priorities of the National Quality Strategy. Stage 2 criteria encouraged the use of certified EHR technology (CEHRT) for continuous quality improvement at the point of care and the exchange of information in the most structured format possible. Addressed functionalities are: Implementation of drug formulary checks; recording of advanced directives for elderly as well as structured clinical lab-test results; providing patient-specific education resources; performing medication reconciliation and sharing patient summaries with units collaborating in those patients' care; sharing related information with public registries and public health agencies.
- In October 2015, CMS released a final rule that modified Stage 2 to ease reporting requirements and to align with other quality reporting programs, such as the Medicare Access and CHIP Reauthorization Act (MACRA) and the Quality Payment Program. The latter offers two streams: Advanced Alternative Payment Models (APMs) or the Merit-based Incentive Payment System (MIPS). This final rule also established **Stage 3** in 2017 and beyond, which focuses on using CEHRT to improve health outcomes. In detail, EHR systems shall provide: Patients' electronic access to their information; advanced reporting schemes to registries and authorities; security risk analysis; comprehensive HIE with collaborating healthcare establishments.

3 EHR Systems' Interoperability

Communicating and cooperating actors involved in a business case have to share data related to the business

process, interpret them to derive the corresponding information to be used for performing the actions needed to jointly meet the business objectives. All three steps of the so-called information cycle [15] are depending on appropriate knowledge and skills available at the actors.

With the advent and further advancement of IT in health, the term interoperability has evolved very much. In its Standards Glossary, IEEE defines interoperability as "ability of a system or a product to work with other systems or products without special effort on the part of the customer" [16]. HIMSS defined 2013 interoperability in healthcare as "the ability of different information technology systems and software applications to communicate, exchange data, and use the information that has been exchanged", thereby distinguishing the three interoperability levels a) foundational, b) structural and c) semantic interoperability. Some years ago the author introduced a more comprehensive definition of interoperability beyond technologies: "Interoperability describes motivation, willingness, ability, and capability to cooperate for achieving common goals or business objectives. It requires knowledge, abilities and skills, shared and adapted a-priori or dynamically at runtime." [17]. Thereby he refined the Knowledge Interoperability level of his originally introduced interoperability levels Data Interoperability, Information Interoperability, and Knowledge Interoperability as presented in Table 2, distinguishing both the information and the organization perspective.

3.1 EHR Systems Architectures

According to IEEE 1471 [18], a system as a collection of components organized to accomplish a specific function or set of functions can be distinguished from its environment, the system's context, which may influence that system by setting constraints. Systems can be decomposed to subsystems or composed to super-systems in a recursive way. A system has one or more stakeholders having special interests in, or concerns to, that system. For meeting the stakeholders' intended objectives of the system, it has to fulfill one or more missions in its environment, also named business objectives.

Every system has an architecture, i.e. according to IEEE 1471, the fundamental organization of a system embodied in its components, their relationships to each other and to the environment and the principles guiding its design and evolution. The architectural description of the system, formally representing the intended artefacts of the system, is organized in architectural views representing a related set of concerns of particular stakeholders. Views are constructed and managed according to viewpoint specifications with their specific language and techniques to represent the view's knowledge (including notations, modeling methods, models, product types, etc.).

ISO/TS 18308 defines EHR architecture as "generic structural components from which all EHRs are built, defined in terms of an information model" [10]. In extension to that definition, ISO TR 20514 states in the EHR Architecture Definition Note "A more descriptive informal definition of an EHRA is that of a model of the generic features necessary in any electronic healthcare record in order that the record may be communicable, complete, a useful and effective ethico-legal record of care and may retain integrity across systems, countries and time...."

From a representational perspective of specifying and implementing EHR architectures, we classify a) data approach (data representation), b) concepts approach (concept/knowledge representation), and c) process/service approach (business_process/service representation). Those three streams partially have their roots in existing systems, in traditional thoughts and methodologies as well as in specific domain-languages and modelling languages. Related to the representational perspective is the modeling perspective. Here we can distinguish a) component-oriented single model approach [19], b) component-oriented dual model approach [20] and c) multi-model approach of component-oriented services [21, 22]. The first two approaches pursue data integration, embedding concepts into structures in the case of the single model approach, or specifying and implementing them using concept models (archetypes) and their implementable object models in the case of the dual model approach. They may be imported into applications to enable functionalities such as workflow concepts and alert mechanisms that are derived from the available data. The third approach realizes functional integration, i.e. interoperability due to the architectural paradigm that is deployed. Those three approaches require different levels of knowledge sharing. The first is based on a-priori distributed knowledge, the second shares data and corresponding concepts, and the third provides facilities to deploy the underlying knowledge.

Regarding the protocol deployed for communication and cooperation, there is a communication focus (message), a document focus (clinical document), and a business process focus (application). Artefacts implementing EHR systems interoperability have evolved during the last 25 years from structured messaging (e.g. EDI, HL7 messaging) over sharing concepts (e.g. openEHR Archetypes[1], EN/ISO 13940 ContSys concepts [23]) - both representing the data/information exchange paradigm - to cooperation at application level (e.g. Web services, FHIR resources). Nevertheless, all those standards-based interoperability approaches are restricted to computer-to-computer communication, representing information according to the domain independent ISO/IEC 10746 Information technology - Open Distributed Processing - Reference Model or to domain-specific information models

[1] An archetype is a model of a clinical or other domain-specific concept which defines the structure and business rules of the concept; computable expression of a domain-level concept in the form of structured constraint statements, based on some reference information model (ISO/TR20514) [5].

Table 2. Interoperability levels

Information Perspective		Organization Perspective
Interoperability Level	**Instances**	**Interoperability Level**
Technical	Technical plug & play, signal & protocol compatibility	Light-weight interactions
Structural	Simple EDI, envelopes	Data sharing
Syntactic	Messages and clinical documents with agreed vocabulary	Information sharing
Semantic	Advanced messaging with common information models and terminologies	Knowledge sharing at IT concept level Coordination
Organization/Service	Common business process	Knowledge sharing at business concept level Agreed cooperation
Knowledge based	Multi-domain processes	Knowledge sharing at domain level Cross-domain cooperation
Skills based	Individual engagement in multiple domains	Knowledge sharing in individual context Moderated end-user collaboration

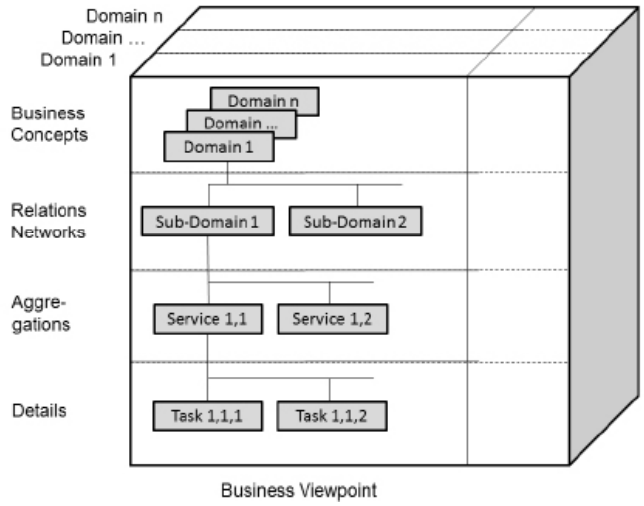

Figure 2. ISO interoperability reference architecture model granularity levels.

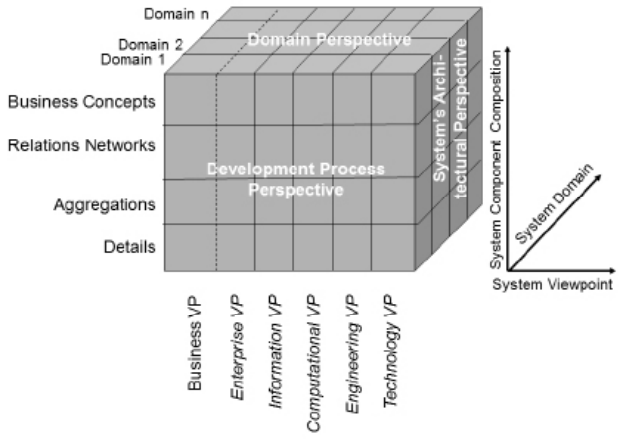

Figure 3. The interoperability reference architecture model.

such as ISO/HL7 21731 Health informatics - HL7 Version 3 - Reference Information Model. [24].

3.2 The ISO Interoperability Reference Architecture

The ISO Interoperability Reference Architecture is an abstract domain-independent representation of systems using Universal Type Theory and corresponding logics. The mathematical concept representation in combination with systems engineering methodologies allows representing any system architecturally (i.e. the system's components, their functions and internal as well as external relations) by generically describing its composition/decomposition as well as the aspects (domains) of the system relevant in a specific context (e.g. business case). For correctly and formally representing the concepts and relations of the domain-specific subsystems involved in that business case, those subsystems are represented by their corresponding approved domain ontologies, resulting in a system-theoretical, architecture-centric, top-level ontology driven approach [25]. The reference architecture model can be used recursively, so representing, e.g., the real-world systems' continuum from elementary particles to the universe (Figure 2).

By combining that Business Viewpoint granularity levels model with ISO/IEC 10746, the Interoperability Reference Architecture Model (introduced in the nineties by the author as Generic Component Model - GCM) as well as the applicable rules - the Interoperability Reference Architecture Framework - (also known as GCM Framework) is completed (Figure 3) [17].

This Interoperability Reference Architecture Model allows consistently transforming and interrelating any domain-specific subsystem's structure and behavior (e.g. domain-specific standards and specifications) by ontologically representing its concepts and relationships at the real world system component's level of granularity. In other words, the domain-specific subsystem (e.g. a domain-specific standard or specification) is re-engineered using the Interoperability Reference Architecture Model, by that way providing a standardized interface to that specification. The ISO Interoperability Reference Architecture has been included in ISO 13606 Health informatics – EHR communication [19] and demonstrates the architecturally correct representation of ISO 13606 based EHR systems and their integration in security and privacy specifications. It supports ontology harmonization or knowledge harmonization to enable interoperability between existing systems, standards and solutions of any level of complexity without the demand for continuously adapting/revising those specifications. In summary the ISO Interoperability Reference Architecture including the GCM Framework principles can be used.

- for analyzing, designing, and implementing EHR systems and underlying architectural models characterized by their components, functionalities, and relationships,
- for defining and realizing migration strategies, but also
- for evaluation, gap analysis and roadmap definition in standards development.

More information on harmonizing existing EHR systems specifications is provided, e.g., in [26].

4 EHR Systems Standards and Solutions

Longitudinal sharable EHR must support collaborative care processes, properly and transparently representing the knowledge of all domains contributing to the care process in a way enabling correct, informed and consistent care decisions. The justification of correctness and consistency in the framework of the disciplines' knowledge can finally only be provided at the real world scenario, as explained in some details in [27]. EHR have to be open, scalable, flexible, portable, distributed, standard-conformant, interoperable at an appropriate level, business process responsive, service-oriented, user-accepted, applicable to any media, trustworthy and lawful. Therefore, the following architectural paradigms have to be met: distribution; component-orientation; a model-driven and service-oriented design taking into account concepts, context, and knowledge; comprehensive business modeling; separation of computation-independent, platform-independent, and platform-specific modeling (thus separating the functional and the logical from the technological view); agreed reference terminologies and ontologies; a unified development process; and advanced security and privacy services embedded in the architecture. Examples of EHR standards, projects and solutions are: HL7 Clinical Documents Architecture (CDA) documents, ASTM E 2369 "Standard Specification for Continuity of Care Record (CCR)", HL7 Continuity of Care Documents (CCD – implementation of CCR in CDA), or Archetypes defined by the openEHR Foundation and in ISO/EN 13606 "Health informatics – EHR communications", but also related IHE profiles or DICOM specifications. Those and more examples have been presented in some details, evaluated and referenced e.g., in [22, 24]. Most of them meet just very few of the aforementioned characteristics.

5 Discussion

5.1 Critical Views on EHR Systems, Standards, Programs and Solutions

Despite all specifications, standards and quite expensive programs, existing EHR approaches - even if certain aforementioned characteristics have been considered in the EHR system design and more or less appropriately implemented - do not accomplish the end users' requirements and expectations. Sue Bowman [28] has highlighted problems with improper EHR specifications and implementations. Many of them show design flaws partially caused by the growing complexity of systems, so not fully meeting the promise of improving care quality, patient safety, and process efficiency. They miss, for example, the needed flexibility and adaptability, but depend on the context and organization they have been designed for. Frequently, the workflow assumed is not the way health professionals actually practice, provoking the deployment of workarounds impacting patient safety. Another risk deals with inconsistencies between structured and free-text data, but also with lack of transparency of ICT processes and actions. In that context, automated processes, e.g. automated data capturing, when inappropriately deployed, can lead to erroneous documentation. That way, inaccurate or outdated information could be entered, especially when using templates. Another challenge is the proper design and implementation of clinical decision support systems, sometimes leading to the so called automation bias. Partially, those problems could be overcome by certifying EHR systems as done in the Meaningful Use (MU) context. However, a multi-center study analyzing experiences in the MU initiative context has demonstrated a series of weaknesses for meeting the overarching objective of care quality, patient safety and care process efficiency [29]. Here, deficiencies regarding quality and accuracy of medication lists and medication reconciliation, but also of problem list and allergy list have to be mentioned. Another critical point is constraining EHR systems functionalities and innovations on the defined incentives, thereby ignoring serious clinical interest in wider developments including the missing consideration and integration of external data describing the patient's behavior and context. Furthermore, clinicians requested better CDS by carefully balancing sensitivity vs. specificity as well as a stronger focus on specific population such as children, developing child-specific standards and norms, and citizens

in rural areas, establishing the educational and technological infrastructure needed. Finally, more flexibility in the application and interpretation of the MU program is recommended.

A summary of all aforementioned requirements has been provided by the AMIA EHR-2020 Task Force on the Status and Future Directions of EHRs [30]. Here, five areas of development and improvement have been defined: simplification and speeding up documentation, refocusing regulation, increasing transparency and streamlining certification, fostering innovation, supporting person-centered care delivery.

Because of high administrative burdens, costs, and partially insufficient outcome, parts of the US EHR Incentive Program will be redesigned, for example promoting the newest US initiative MyHealthEData [31].

5.2 Future Directions

For guaranteeing data quality, integrity and correctness, EHR systems in general, but especially when moving to PHR systems, need implementing a quality management system and governance management, but also solving legal, accessibility and usability issues. The infrastructural services necessary in the sense of flexible and adaptive cognitive systems shall comprise context monitoring, text analytics (automated text analysis), natural language processing (NLP), etc.

For properly integrating clinical data, semantic mapping, a data lake infrastructure supporting multiple file formats for data intake, but also the aforementioned service of text analytics and NLP are inevitable for converting unstructured into structured formats.

Traditionally, EHRs are first of all designed to provide actors involved the information they need to participate in the care process. They collect data within a specific workflow, not supporting data utilization outside that workflow including the deployment of transactional data. When looking for future requirements to meet the healthcare transformation challenge presented in Table 1, it is impossible to provide EHR systems for functionalities such as artificial intelligence and machine learning, real-time analytics on transactional data, dynamic binding to data from any system, making data management and services available to any system. Therefore an additional layer on top of the EHR system must be introduced, interconnecting with the other layers via open APIs like Health Catalyst's Data Operating System (DOS). That way, the data operating ecosystem creates real-time insight to meet the aforementioned healthcare transformation challenges of quality care, patient safety and care process efficiency and provides them back to the healthcare ecosystem with its core component EHR system. In detail, following services have to be provided [32]:

- Real-time analysis of data from multiple data sources to monitor patients;
- Patient dashboards to monitor a patient's overall health and key improvement measures;
- Early detection of at-risk patients;
- Discovery of population health trends;
- Custom rules based on specific data triggers, which can be used to create follow-ups if certain patient health indicators are met;
- Performance insights on staff productivity;
- Data mining capabilities to discover insights on different patient conditions; and
- Data analysis to determine the most effective treatment plans for patients.

An early and far simpler approach to such a layered EHR system architecture has been defined and implemented with the Canada Infoway EHR Solution Infostructure [33].

Based on the current developments, the adoption of new and emerging technologies such as artificial intelligence and machine learning, so enabling the aforementioned flexibility and adaptability and accommodating any thinkable use case could be pushed by Google's open source Cloud Healthcare API, introducing a second tier above the EHR system. Google's API is based on HL7's FHIR API. As alternative to Google's Cloud Healthcare initiative, Amazon Web Services (AWS) or Microsoft's Azure have to be mentioned.

Combining the aforementioned Canada Infoway EHR Solution Infostructure and its German adoption the author was responsibly involved in with the Cancer Care Ontario Enterprise Architecture [34] and elements of IBM's Clinical Decision Intelligence approach considering the patient's environmental and contextual conditions by cognitive computing [35], the essential elements of a future EHR System Enterprise Architecture can be derived as shown in in Figure 4.

Following those advanced approaches increases the importance of data governance, but also of security, privacy and trust in the ecosystem.

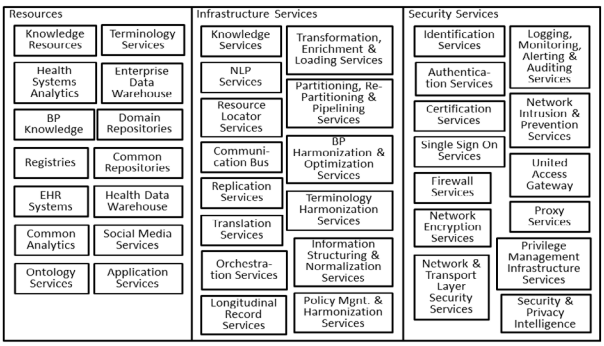

Figure 4. Essential components of a future EHR system enterprise architecture.

6 Conclusion

Over the 50 years of developing EMRs/EHRs since the pioneering developments of Lawrence (Larry) Weed, resulting in a series of international or national standards and projects, the main focus was put on the EHR structure, but less on EHR functionality. In consequence, there was a strong and almost "religious" competition between the different EHR types and EHR approaches presented in the paper. Hopefully it became clear that the focus has to change to services, implemented as data services, but justified through the disciplines creating those data as description and representation of those domains' concepts.

That way, EHR systems will master the ongoing healthcare transformation according to the health systems' organizational, methodological and technological paradigm changes, thereby meeting requirements and expectations of domain-specific stakeholders including the patients.

Despite all advancements in data-driven solutions, any project has to start in modeling the business domain(s), where the stakeholders define requirements, base concepts and relations, etc., according to the modeling best practice principles [36, 37, 38, 39, 40]. Only in the real world domains, correctness and consistency of concepts and rules, i.e. ontologies, can be justified. Otherwise we face the problem of many IT and informatics projects that the designed map is perfect, just the landscape represented is wrong.

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From eHealth to ePatient: The Role of Patient Portals in Fostering Patient Empowerment

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Abstract

Background: Health IT adoption is high in Austria, but health IT targeted at the patient is still rare.

Objectives: To analyse the shift from eHealth to ePatient and the role that patient portals may have in this shift, from an Austrian perspective.

Methods: Analysis of the situation in Austria regarding the use of eHealth and patient portals.

Results: While eHealth applications are broadly used in Austria, only few applications address the patient as user and aim at facilitating patient empowerment. Patient portals are one approach to foster patient empowerment. In Austria, a national patient portal is introduced at the moment, but only with limited functionalities. Systematic reviews show that the evidence on the impact of patient portals on patient empowerment is still unclear, which may explain low adoption rates. It seems to be still a long way to support a new generation of ePatients who are equipped, enabled, empowered and engaged in their health and health care decisions.

Conclusion: Patient portals and other eHealth interventions aiming at fostering patient empowerment can only show impact when health care professionals are willing to engage in a true partnership with the patient, and when patients are willing to take over responsibility for their own health management.

Keywords

Medical informatics; Evaluation studies; Telemedicine; Patient participation; Patient portals

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1 Introduction

As in many other countries, health care in Austria is not possible any more without the use of information and communication technologies (health IT). The usage of health IT has strongly increased in the last decades due to demographic change, rising costs of health care, medical progress, and technological achievements.

In the 1990th and 2000th, both private and public hospitals started to introduce health IT such as administrative systems, physician and nursing documentation systems, order entry systems, patient data management systems, or picture and archiving systems [1]. Today, many hospitals have introduced mobile tools (such as tablets or laptops) to support information access and clinical documentation at the patients' bedside.

In 2005, the Austrian government started to establish a national electronic health record system (Elektronische Gesundheitsakte, ELGA) [2]. ELGA connects hospitals, nursing homes and physicians, and allows them to exchange patient-related information such as discharge letters, lab findings, radiology findings, and information on prescribed and dispensed medication [3].

In 2015, the ELGA patient portal went live. This patient portal allows patients to access all patient-related information stored within ELGA. It also allows patients to grant access rights to specific health care providers or to relatives. Patients may also decide to fully opt-out out of ELGA. In 2014, less than 12% of Austrian citizens planned to opt-out. In 2018, less than 4% of all citizens had really opted out [4].

The ELGA patient portal does not present much information at the moment, as health care providers are just starting to make information available via ELGA. Currently it is unclear whether the ELGA patient portal will contribute to a more patient-centered care in Austria, and whether it will empower the Austrian patients to take over a more active role in their health care.

The objective of this presentation is to discuss the change from eHealth to ePatient from an Austrian perspective, and to analyse the role of patient portals may have in this shift.

2 From eHealth to ePatient

The term eHealth emerged around 20 years ago. eHealth can be defined as the "use of emerging information and communication technology, especially the Internet, to improve or enable health and healthcare" [5]. eHealth allows health care providers to exchange patient-related information. That way it supports patient-centered, integrated care.

Austria is a country with a high eHealth penetration. High IT adoption rates especially in hospitals, but also in physicians' offices as well as introduction of the national electronic health record ELGA clearly illustrate this [6].

But eHealth is not only about communication between health care providers and health care institutions. eHealth is also about communication between health care providers and the patient. And here, Austria seems not so strong at the moment. Typical patient-centered applications such as appointment scheduling, secure messaging, electronic ordering for medication refills, telemonitoring or eVisits are seldom available to patients. Only telemonitoring applications show a higher penetration in Austria [6]. For example, in Tyrol, telemonitoring is routinely offered to patient with heart failure since 2017 [7].

As health care providers show some reluctance to offer eHealth applications for their patients, patients themselves have started to use eHealth applications on their own. Social networks of patient support groups proliferate, personal health records are used in various forms especially by chronic patients, and mobile health and quantified health applications show increasing usage rates [6].

But eHealth is not only about IT-supported communication. Rather, eHealth is "also a state-of-mind, a way of thinking, an attitude, and a commitment for networked, global thinking, to improve health care" [8]. And this new perspective also includes "a new relationship between the patient and health professional, towards a true partnership, where decisions are made in a shared manner" [8]. This new relationship is based on patient encouragement and patient empowerment. And here, Austria seems to be only at the beginning. But let's look a bit closer on the concept of patient empowerment first.

Patient empowerment is based on a philosophy which views humans as having the right and ability to choose by and for themselves. Patients are responsible for their choices and the consequences of their choices. Patient empowerment means that patients are able to make autonomous, informed decisions within a true partnership between patient and health care professional [9, 10].

The evolving role of the patient in the last 50 years can be described in five steps [11], as summarized in Figure 1:

The patronized patient, where the physician was the only one to decide on the next steps of care.

The informed patient, where the patient has at least to give his informed consent to a treatment decision.

The mature patient, where the patient was involved in decision making before the final treatment decision was made.

The autonomous patient, where the patient was considered as equal partner and where a shared decision marking between physician and patient took place.

The empowered patient, where the patient is put in the center of any decision making.

What comes next? Probably we will see the ePatient, willing to be empowered and to use health information technologies to support his well-being and his medical care. To be more specific, the term ePatients describes individuals who are "equipped, enabled, empowered and engaged" in their health and health care decisions [12].

Technologies supporting patient empowerment of ePatients are, among others, internet-based information resources, social networks, internet-based patient support groups, personal health records, mobile health tools, and patient portals. Evidence shows that patients want to be empowered and that empowered patients show better clinical outcome [10].

Now let's have a closer look at patient portals and how they may support patient empowerment.

3 Patient Portals and Patient Empowerment

A patient portal can be defined as provider-tethered applications that allow patients to electronically access his health information that is documented and managed by a health care institution [13]. A simplified categorization may describe three levels:

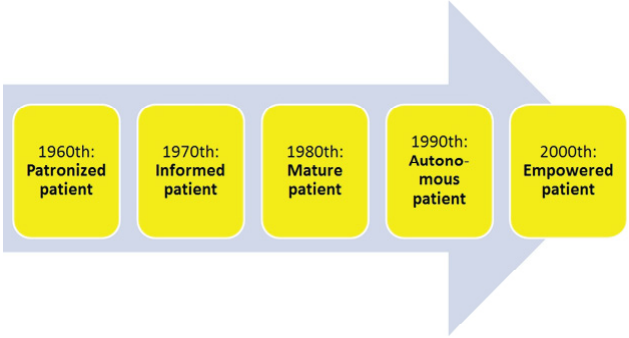

Figure 1. The development of patient empowerment [11].

Figure 2. Jana Zvarova at the eHealth 2016 conference in Vienna, May 25th, 2016, talking about international cooperation with Klaus-Peter Adlassnig.

- Level 1: Patient portal allows patient access to clinical data from electronic patient records from one or more health care institutions (e.g. discharge letters, lab values, medication information).
- Level 2: Patient portal supports communication between the patient and a healthcare provider (e.g. appointment scheduling, secure messaging, ordering of medication refills, eVisits).
- Level 3: Patient portal offers disease-specific functionalities as part of a systematic disease management (e.g. personal reminders, clinical guidelines, educational material, self-documentation, feedback).

In the United States, Meaningful Use criteria have accelerated patient portal adoption in the last years, a recent survey showing that 57% of health care provides offer a patient portal [14].

In Austria, health care institutions are not obliged to offer patient portals, and thus very few have started projects in this direction. For example, Steiermärkische Krankenanstalten, a network of 12 hospitals in Styria, offers a patient portal that contains discharge letters and radiology findings [15], being equivalent to the portal level 1 described above. In this portal, appointment scheduling for patients is planned, but not yet realized.

Since 2015, the national electronic health record ELGA is made available. ELGA includes a patient portal for all citizens in Austria. However, ELGA only offers level 1 functionality at the moment. Thus, patients can access discharge letters, lab and radiology findings, and (starting in 2018) information on prescribed and dispensed medication. Further functionalities for patient empowerment, such as functionalities supporting communication with providers or disease-specific functionalities, are not planned yet.

So, summarizing, patient portal adoption in Austria is quite at an early stage. Several reasons can be assumed for this low adoption: Health care professionals may be concerned in giving too much clinical information to their patients; health care professionals or patients may be concerned about possible data security issues; the impact of patient portals may be unclear; or the costs for patient portal development may outweigh the expected benefits. At the moment, no systematic assessment of these barriers has been conducted from an Austrian perspective. An earlier study, however, found skepticism among Austrian physicians with regard to electronic health records in general [16].

Whether patient portals really can have a positive impact on patient empowerment or not seems to be quite unclear at the moment. First systematic review showed a low number of studies and insufficient evidence [13, 17]. This is an unsatisfying situation giving the premise of Evidence-Based Health Informatics to provide the best evidence to support decisions related to health IT introduction and usage [18].

Therefore, at the moment, a Cochrane review was started by our group to systematically evaluate the most recent evidence on the impact of patient portals on patient empowerment [19]. A still running systematic literature search identified only 12 randomized studies, most of them from the United States. Data analysis is just underway.

4 Discussion

We can assume that success of patient portals will not come from specific functionality, but from "successfully communicating the idea that patients can effectively manage their own illness" [12]. Or, to be more specific: Patient portals and other eHealth interventions aimed at improving patient empowerment will only show impact:

- When health care professionals are willing to engage in a true partnership with the patient and to give up power; and
- When patients are willing to take over responsibility for their own health management.

Both requirements may be considered questionable at the moment. What can medical informatics contribute here? In my opinion, we must understand that information system have to be considered from a socio-technical perspective [20]. This means that health IT is not about technology, but about how technology can help to transform healthcare. eHealth is about changing roles, about people, and about changing power relationships.

Or as Sherry Turkle from MIT put it: „The key question we must ask is not what technology will be like in the future, but rather what we will be like" [12].

5 Conclusion

The challenges of electronic health records and patient portals can only be understood and addressed from an international point of view. While countries may show differences in healthcare organization, the challenges are identical for all countries: How can we provide affordable health care for all citizens? And how can eHealth contribute to this objective?

Jana Zvarova whom we are commemorating in this special issue was always a strong supporter of international communication and collaboration in medical informatics, both in research as well as in education. Already in the 1980th, she organized meetings and conferences with colleagues from abroad and was ever-welcomed partner in international projects. She was also an active and creative member of IMIA and EFMI.

When we decided to develop the Austrian annual eHealth conference into an international conference in 2016, Jana Zvarova was one of the first to accept the invitation to serve in the International Scientific Programme Committee of this Austrian eHealth conference. In this role, she helped to promote the conference especially in the eastern part of Europe. She also gave us the honor to participate in person to the first international edition of the Austrian eHealth2016 conference in Vienna in May 2016 (Figure 2), showing her strong commitment and full support for international cooperation.

We will remember her as a friendly, supporting, and creative scientist with strong international vision, and as a friend!

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Big Data, Biostatistics and Complexity Reduction

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Abstract

The aim of this paper is to overview challenges and principles of Big Data analysis in biomedicine. Recent multivariate statistical approaches to complexity reduction represent a useful (and often irreplaceable) methodology allowing performing a reliable Big Data analysis. Attention is paid to principal component analysis, partial least squares, and variable selection based on maximizing conditional entropy. Some important problems as well as ideas of complexity reduction are illustrated on examples from biomedical research tasks. These include high-dimensional data in the form of facial images or gene expression measurements from a cardiovascular genetic study.

Keywords

Biostatistics; Big data; Multivariate statistics; Dimensionality; Variable selection

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1 Introduction

Big Data in biomedicine represent an important and perspective but still not sufficiently utilized capital with a potential to improve the diagnosis, prognosis and therapy for individual patients. A proper biostatistical analysis of Big Data is one of key components (or even accelerators) of the development of reliable clinical decision support tools and has to face difficult challenges [1, 2].

Exploiting Big Data in biomedical research and practice also allows to contribute to improving the decision making process of clinical decision support, which requires to solve classification tasks. The aim is to learn a classification rule over a training dataset allowing to assign a new sample (individual) to one of the groups, e.g. according to the diagnosis and thus to decide for a particular diagnosis. It is however not so common that biomedical data have a very larger number of observations n (i.e, the number of samples or patients). More commonly, Big Data in biomedicine have the form of high-dimensional data with a small or moderate n, but a large number of variables p (symptoms and signs, results of biochemical or laboratory measurements etc.).

If Big Data are also contaminated by noise, which is a typical situation, then a pre-processing and cleaning the data together with a consequent complexity reduction represent crucial preliminary steps of each analysis [3, 4]. Typical examples of such applications, which cannot be appropriately analyzed by standard methods, include molecular genetic studie, functional magnetic resonance imaging (fMRI) of brains [5], or longitudinal data.

This paper can be understood as an attempt to formulate our experience with analyzing biomedical Big Data, especially from the point of view of reducing their complexity, which makes the process of data analysis more accessible by means of multivariate statistical tools. We recall basic challenges of Big Data analysis, overview major approaches to their complexity reduction and illustrate their principles on some recent biomedical research tasks. Section 2 introduces the problem of Big Data and its analysis in biomedicine. Section 3 presents basic principles of complexity reduction. Particular methods are described in the consequent sections accompanied by examples, namely the principal component analysis in Section 4 for variable selection by maximal conditional entropy in Section 5. Finally, partial least squares for regression are described in Section 6, which are often transferred also to classification problems. Hypothesis tests are discussed in Section 7.

2 Big Data in Biomedicine

Origins of multivariate statistics trace back to Karl Pearson (1857-1936), who developed the first multivariate statistical methods for the needs of anthropology and forensic science. The first applied statisticians of the beginning of the 20th century are at the same time well known by biologists. In 1911, Pearson founded the first statistical department at the world in London called Department of Applied Statistics, where

he was appointed as professor. The interdisciplinary department included also biometric and eugenic laboratories and the boundary between statistics and biological sciences was not clear at that time. Pearson introduced also the concept of contingency tables, which is until now a general statistical concept for tables of counts (i.e, of a discrete variable). Pearson analyzed them when trying to prove the evolution theory by means of statistical methods. Pearson defined contingency as a broadly discussed phenomenon describing randomness or unpredictability within evolution with influence on the whole species of organisms. The concept of contingency tables remains in statistics as one statistical concepts with a biologically motivated name.

The amount of data with a potential to improve healthcare for an individual patient rises enormously. Such big data represent a valuable capital with an opportunity for a dramatic change of current practices of health care, accelerating the development of information-based medicine [3, 4]. So far, big data in the psychiatric context are measured primarily for the research purposes, while they have the potential to contribute to improving the efficiency of clinical decision making and patient safety.

Low-level computer tasks applied on the new types of data (including Big Data) have been described in recent monographs on health informatics [6]. So far, intensive attention has paid to technological aspects concerning the storage of big medical data in large databases and their transfer, protection (data security issues), sharing, lossless compression, information retrieval, and appropriate visualization. An important issue is also integration of various e-health systems allowing integrating individual data with data about the current care, brain imaging results, presence of risk gene variants etc.

The analysis of the clinical data by means of methods of multivariate statistics and data mining becomes a necessity as the volume of data namely grows not only rapidly but also much faster than the ability to analyze and interpret them. Unfortunately, the crucial important question how to acquire new medical knowledge by a proper analysis of big medical data reliably has obtained less attention. An example of an improper interpretation of statistical result is the paper by Nordahl H et al. [7], where low education is denoted as a risk factor of cerebrovascular stroke, while it is only an instrument associated with true risk factors (e.g. lifestyle or stress).

Traditional statistical methods are unsuitable for any form of Big Data. Therefore, dimensionality reduction (complexity reduction, variable selection) is generally recommended as the initial step of the analysis of data with a large number p of variables observed over n samples. It can actually improve the result of a subsequent analysis in spite of losing some relevant information.

On the other hand, the idea of parsimony (i.e, reducing the set of variables to a too small number of relevant ones) has been also criticized [8] and variable selection may be optimized for a classification or clustering context [9]. Experience of applied researchers is critical for not being as good as presented in theoretical papers on simulated data [10]. We also should not leave out that in some clinical fields, data analysis has to face their own challenges and fulfill field-specific requirements.

3 Overview of Complexity Reduction

Complexity reduction is a general concept including any approach to simplifying the analysis of data of various forms, e.g. finding suitable relevant features from medical images of the brain, voice records, narrative text of health reports etc. Various types and formats of biomedical data require a broad spectrum of sophisticated methods for their analysis.

In recent years, new specific complexity reduction approaches have proposed within the fields of multivariate statistics, computer science (machine learning) or information theory [11, 12, 13, 14]. This section recalls the most common methods used in biomedical applications, however only for the context of numerical data. Then, the concept of complexity reduction is usually replaced by dimensionality reduction, which can be understood as a more specific version of a general complexity reduction.

In the whole paper, we consider numerical (discrete or continuous) data with the dimensionality denoted as p, i.e, with p variables corresponding to e.g. measure symptoms or laboratory measurements measured over n samples (individuals). In general, dimensionality reduction may bring several important benefits:

- Simplification of subsequent computations
- Comprehensibility (e.g. allowing to divide variables to clusters)
- Reduction or removing correlation among variables
- A possible improvement of the classification performance (which happens however only occasionally).

If p is large, and especially if p largely exceeds the number of observations n, numerous standard classification methods suffer from the so-called curse of dimensionality. They are either computationally infeasible or at least numerically unstable for such high-dimensional data [15, 16]. In such a case, dimensionality reduction is a necessity. We distinguish between supervised and unsupervised complexity reduction methods, where supervised ones are tailor-made for data coming from two or more groups, while the information about the group belonging is taken into account. None of the approach is uniformly the best across all datasets.

Variable selection methods extract a relevant subset of the set of the original variables. Their important examples include:

- Statistical hypothesis tests (which are however used only to rank variables in order of evidence against the null hypothesis, instead of computing a p-value).

- Variable selection based on maximal conditional entropy (Section 5).
- MRMR variable selection (Maximum Relevance Minimum Redundancy) [17].
- Bayesian variable selection methods.
- Wrappers or filters (or embedded methods).
- *t*-scores corrected for marginal correlations.

Tailor-made variable selection approaches for regression models include:

- Lasso estimation.
- Partial least squares (Section 6).
- Linear Models for Microarrays (limma).
- Sliced inverse regression.
- Elastic net.
- Regularized discriminant analysis (RDA).
- Shrunken centroid regularized discriminant analysis (SCRDA).
- Smoothly clipped absolute deviation (SCAD).

Feature extraction methods search for linear (or nonlinear) combinations of variables, while retaining all variables in the model.

Prominent examples of linear methods include:

- Principal component analysis (Section 4).
- Robust versions of principal component analysis [18].
- Factor analysis (FA).
- Linear discriminant analysis (LDA, which is however aimed primarily at classification).

While nonlinear include:

- Independent component analysis (ICA).
- Correspondence analysis.
- Methods of information theory.

4 Principal Component Analysis

Principal component analysis (PCA) represents the most commonly used complexity reduction method in biomedical applications. The examples show that PCA is very often used for data observed in groups, although this is not suitable due to its unsupervised nature as investigated already by Mertens BJA [19].

4.1 Method

The aim of PCA is to replace the total number of n observations, which are p-variate, by a set of transformed n observations with a smaller number of variables (dimensions). Thus, the original variables are replaced by a small number of (say s) principal components, where the user may choose a suitable s fulfilling $s<min(n,p)$. New s-dimensional observations represent mutually uncorrelated (orthogonal) linear combinations of the original variables with the ability to explain a large (more precisely the largest possible) portion of variability of the data [11].

The empirical covariance matrix S is ensured to be symmetric and positive semi definite with non-negative eigenvalues and its rank does not exceed $mim(n,p)$. Because the sum of eigenvalues of a general square matrix is equal to the sum of its diagonal elements (i.e, its trace), this is for the case of a covariance matrix equal to the sum of variances of individual variables.

PCA may bring a remarkable reduction of computational costs, especially for small values of the constant s. The contribution of the i-th principal component ($i=1,\ldots,p$), i.e, the component corresponding the i-th largest eigenvalue to the explanation of the total variability in the data can be expressed as the relative contribution of the corresponding eigenvalue. A different (not equivalent) approach may be based on computing principal components from the empirical correlation matrix, which is recommended in case of big differences in the variability of individual variables.

Formally, PCA projects individual observations to the subspace generated by s eigenvectors of the matrix S, which belong to the largest eigenvalues. Then, consequent computations are performed in a space generated by these eigenvectors and the computations replace each observation by the resulting linear combinations. A popular tool for selecting a proper value of s is the scree plot, which is shown in Figure 1 for a dataset described later in Section 4.2. It exploits the fact that the total variability in the data is equal to the trace of D and thus also to the sum of the eigenvalues of S.

Commonly, the user demands the selected principal components to explain at least a given percentage of the total variability, which formulates a requirement on the eigenvalues. Particularly, if the selected principal components should explain e.g. 80% of the total data variability, this means to select such number s of principal components so that the sum of s largest eigenvalues exceeds 80% of the sum of all eigenvalues.

Standard dimensionality reduction methods suffer from the presence of measurement errors or outlying measurements (outliers) in the data [20, 21]. We may recommend performing multivariate methods including PCA by robust alternative of standard approaches. Robust versions of PCA, which are resistant (insensitive) to outliers, have been developed [18]. If robust PCA is based on eigen-decomposition of a robust covariance matrix estimator, the resulting robust principal components are uncorrelated.

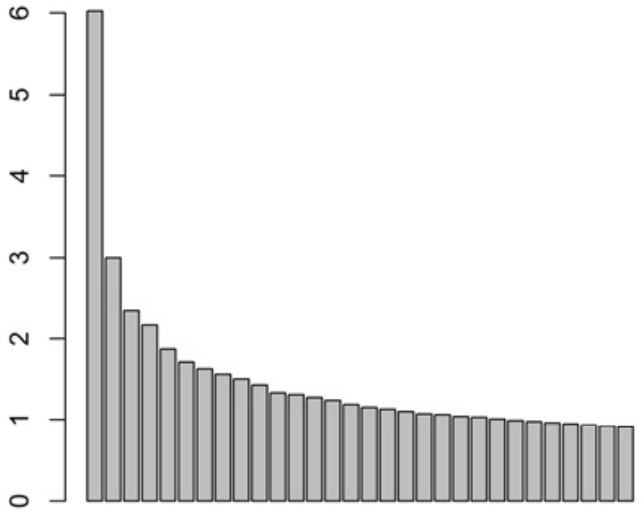

Figure 1. 30 largest eigenvalues of the matrix S in the example of Section 4.2.

4.2 Example: Diagnostics of Cardiovascular Diseases

In a cardiovascular genetic study performed at the Center of Biomedical Informatics in Prague, headed by Prof. Jana Zvárová, a research of gene expressions was performed in 2006-2011 to construct a decision support system based on clinical and gene expressions data [22]. The microarray technology was used to measure average gene expressions of more than 39 thousands gene transcripts across the whole genome. The aim was finding sets of genes, which are useful in the process of diagnostics of (new) individuals.

As it is a typical situation in molecular genetics that there are thousands or tens of thousands of variables (gene expressions) measured on a sample of tens or hundreds (at maximum) of patients, we perform a dimensionality reduction at first and proceed to constructing a classification rule only afterwards. PCA was performed for various values of s and the results reveal that there is no remarkable small group of variables responsible for a large portion of variability of the data and the first few principal components seem rather arbitrary. We used the simplest regularized version of linear discriminant analysis (LDA) [23] to learn a classification rule allowing assigning a new individual to one of the given categories according to the diagnosis.

If s=10, the constructed classification rule was not able to overcome a classification accuracy of 75%. Only if the number of selected principal components was raised to the maximal possible value, which is equal to the number of observations in the data set, the classification accuracy in a leave-one-out cross validation study was able to further increase above 90%. This is the situation with infeasible standard LDA, but the regularized version does not suffer from curse of dimensionality and represents a reliable tool with no tendencies to overfit [23]. Results with a large s allowed obtaining results with a clear interpretation, because there seems no small set of very dominant genes, which would be sufficient for the subsequent classification task. On the other hand, there is a large number of genes with only a small influence on the classification task, which cannot be however neglected.

The results without reducing the dimensionality to a small number of principal components allowed to predict the risk of a manifestation of acute myocardial infarction or cerebrovascular stroke in the next 5 years for a particular patient. If he/she has already undergone an acute myocardial infarction, then the resulting principal components of gene expressions are able to predict the risk of a more severe prognosis or a relapse [22]. Patients with a high risk of a future manifestation of a cardiovascular disease can be consequently monitored, which can increase the patient safety and lead to a more effective and safer care for patients with a life-threatening risk.

4.3 Example: Face Detection

Another example is devoted to the face detection task in a database of images coming from the Institute of Human Genetics, University of Duisburg-Essen, Germany (projects BO 1955/2-1 and WU 314/2-1 of the German Research Council) [24]. This database contains 212 grey-scale images of the size 192 times 256 pixels, each image corresponding to a different person. The persons are volunteers in the age between 18 and 35 years of German origin without a manifested genetic disease. The images were photographed under standardized conditions; the faces do not differ much in size and are also rotated in the plane by small angles. Therefore, eyes are not in a perfectly horizontal position in such images.

The work aimed at constructing a decision support system [25]. The aim was to propose a mouth detection method for the sake of a decision support system for the diagnostics of genetic diseases in children with dysmorphic faces. Thus, it was required to have a method which is comprehensible and useful also for genetic patients with a facial dysmorphia. From the given database of images of the whole faces, we manually localized and selected a database of 212 mouths and 212 non-mouths of size 26x56 pixels. Particularly, a non-mouth was selected within each image, which has the largest similarity with the mouth in the same image by means of the correlation coefficient with a bearded template [24]. These images are however transformed to vectors, i.e, with length p=1456.

We use the projection pursuit (PP) algorithm for the robust PCA of [18] implemented in library pcaPP of the R software. The PP is a general approach for finding the most informative directions or components for multivariate (high-dimensional) data. Such dimensionality reduction is based

on a robust measure of spread of the data, taking into account the outlyingness of each data point. Candidate directions for the principal components are selected by a grid algorithm optimizing such objective function only in a plane, while the subsequent components are added in the later steps.

We computed 5 main principal components from the mouths and non-mouths by the PP algorithm. As the robust method allows to identify the outliers, we have revealed more reliable data point in the top part of the images, corresponding to the face parts above and aside from the lips. On the other hand the (potential) outliers are located on the boundary of the mouth or in the bottom part of the images in the area between the mouth and the chin.

Further, the classification task itself is solved by the standard quadratic discriminant analysis (QDA), which would not be otherwise feasible for high-dimensional data with a number of variables exceeding the number of observations. The classification with QDA yields a correct performance of 100% in a leave-one-out cross validation study, which represents a standard attempt for an independent validation [26].

5 Variable Selection based on Maximal Conditional Entropy

An important class of supervised variable selection procedures is based on principles of the information theory. This section recalls a stepwise variable selection approach based on maximizing conditional entropy. Such approach was applied within a prototype of a system for clinical decision support of [22]. We investigated the performance of the system again on the molecular genetic data from the Center of Biomedical Informatics (2006-2011).

5.1 Method

Data observed in two groups are considered. The method is able to reduce the set of all variables by a forward procedure optimizing a decision-making criterion. We consider a set of variables and the classification rule should be based on them over a training dataset. We define Y as an indicator variable, assuming that it equals 1 if and only if a given sample belongs to the first group. We understand Y as a binary response of the observed variables, which play the role of regressors; these must be however categorized, i.e, replaced by categorical variables with at most 4 categories.

It will be necessary to measure the contribution of a given variable (say X) to explaining the uncertainty in the response. This will be quantified by means of the conditional Shannon information. The first selected variable maximixes the conditional Shannon information with the response among all variables i.e, is the most relevant variable for the classification task. Further on, selecting the variables may be described in the following way. If variables $X_1,..,X_s$ have been already selected as the most relevant s variables, the next variable (say X_{s+1}) is selected as that variable fulfilling the requirement.

$$d(Y \mid X_1,\ldots,X_s,X_{s+1}) = \max d(Y \mid X_1,\ldots,X_s,X), \qquad (1)$$

where all variables X not present in the set $\{X_1,\ldots,X_s\}$ are considered. The expression d in (1) is the conditional Shannon information. Thus, a variable very relevant for the classification task is chosen taking into account the dependence of the selected variables. Finally, only such variables for the consequent classification analysis are considered, which contribute to explaining more than a given percentage of the inter-class variability of the data; the choice for this percentage will be discussed in the example of Section 5.2.

5.2 Example: System SIR

A prototype of a clinical decision support system called SIR (System for selecting relevant Information for decision suppoRt) was proposed and implemented in [22], exploiting a sophisticated variable selection component. It contains various tools of supervised learning methods to learn the sophisticated classification rule in order to support a diagnostic decision making The main advantage of the system is suitability also for high-dimensional data obtained e.g. in molecular genetic studies.

The system SIR can be described as an easy-to-use web-based generic service devoted to data collection and decision support with a sophisticated information extraction component. It is proposed for being used mainly for general practitioners in the primary care, but it is able to handle data from any area of medicine. The decision making of the SIR requires data from a (sufficiently large) clinical study in order to construct the optimal classification rule for the decision making problem.

Data collected within a clinical study represent the training database of the SIR, which can import the whole data set from a clinical study automatically together with a data model. The maximum entropy variable selection of Section 5.1 is used. All variables selected by the variable selection procedure are required to enter the decision support system, which can be performed through the automatically generated interface from an electronic health record (EHR) or health information system (HIS), although a manual input of data is also possible.

The clinician must specify the prior diagnosis before entering the data to the SIR, because he/she is the only one to carry the legal responsibility for the clinical decision. Now the SIR can be used through the web service to obtain a diagnosis support. Then, the clinician is asked to manually select his/her final decision and only if it is not in accordance with the SIR, the clinician writes a short text justifying the decision. The system allows quantifying the influence of an additional examination (variable) on the diagnostic decision. Additionally, the dimension reduction procedure

may be extended to consider also costs of obtaining each clinical or laboratory measurement.

The prototype of the system SIR was verified on a different data set from set from the previously described cardiovascular genetic study [22]. Clinical and gene expression measurements were measured on 59 patients with infarction, 45 patients having a cerebrovascular stroke, and 77 control persons without a manifested cardiovascular disease.

If no dimensionality reduction is performed, a regularized LDA yields the classification accuracy 0.85, which is defined as the percentage of correctly classified samples.

We applied the variable selection described in Section 5.1 to the set of 8 personal and clinical variables. Requiring that the selected variables contribute to at least 90% of the intra-class variability of the whole set, we selected 5 variables. At the same time, the variable selection was applied to the set of more than 39 000 gene transcripts, where 245 of them were selected again based on the requirement to contribute to more than 90% of the variability. The classification accuracy in a leave-one-out cross validation study with the 5 variables and 245 genes is equal to 0.85, while it drops to 0.65 if 5 variables are used with 10 genes selected by a MRMR [17] variable selection. These results were obtained with a support vector machine classifier with a Gaussian kernel, which outperforms a number of other standard classifiers.

6 Partial Least Squares

Partial least squares (PLS, also projection to latent structures) can be presented as a supervised dimensionality reduction connected with a regression or classification method [12]. While the PLS is a common method in biomedical or chemometric applications, the method for parameter estimation is more complicated compared to other standard methods of multivariate statistics. The method replaces original variables by new ones, which will be denoted as latent variables, although they are commonly denoted also as principal components or predictive components. A real data set will be described first, which was selected as an example of a study, for which the PLS represents a suitable tool, while general principles of the method will be overviewed afterwards.

6.1 Example: Toxicity of Rat Liver

Let us consider gene expression data from the liver toxicity experiment of [27] in which the total number of n=64 rats was exposed to acetaminophen. The structure of the data is shown in Table 1. The rats were divided to 4 groups. A necropsy was performed on the liver of each rat, while it was performed 6 hours after exposure in the first group, 18 hours in the second group, 24 in the third and finally 48 hours in the fourth group. The data set contains gene expressions measured for p=3116 selected genes on each of the rats. These data were already pre-processed and normalized in a standard way and the remains to learn a classification rule based on the data.

The analysis of the data observed in this experiment requires learning a classification rule allowing to assign a new observation to one of the four given groups according the time interval between the exposition and necropsy. Its intrinsic dimensionality reduction remarkably simplifies the classification, which is illustrated in Figure 2 depicting two major latent variables computed by the PLS-DA. The PLS method allows to visualize the results. In regression tasks, the contribution of individual latent variables to the variability of the response may be evaluated. In classification, the contribution of latent variables to the separation among the groups may be evaluated. This is a similar property with the PCA, where the contribution of individual principal components to the variability of the original data may be evaluated, as explained in Section 4.1.

In the example only two of these latent variables are sufficient to construct a reliable classification rule practically with any classification method. The classification to four groups with QDA attains 100% in a leave-one-out cross-validation study.

Table 1. Data on the toxicity of rat liver in the example of section 6.1.

Rat	Time to necropsy	Gene 1	…	Gene 3116
1	6	0.051	…	-0.034
2	6	0.015	…	-0.079
…	…	…	…	…
64	48	-0.014	…	-0.017

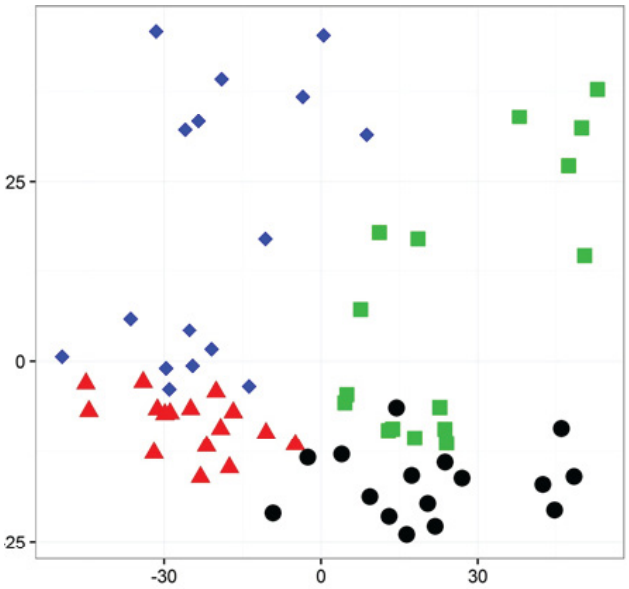

Figure 2. Graph of the association between two latent (predictive) components computed by PLS-DA in the example of Section 6.1, where the contribution of individual observations to one of the groups is given by the shape (circle, square, triangle, and rhombus).

6.2 Method

The PLS was originally proposed for the linear regression model. Thus, the regression version of the PLS remains to be commonly denoted as PLS-R. Formally, PLS-R exploits the standard linear regression model, where Y can be a matrix corresponding to a multivariate response explained by regressors X. The PLS-R method combines the regression task (parameter estimation) with dimensionality reduction in the following way. It searches for the optimal set of latent variables for regressors and also an analogous set for the multivariate response. Instead of X and Y, their linear combinations are considered, which have a smaller dimensionality but the maximal mutual covariance.

Various numerical studies indicated the suitability of the PLS-R method in some applications, especially if one or more of the following situations are true:

- The model suffers from multicollinearity.
- p is large.
- The errors e has a large variability.

Commonly, the PLS method in the regression version is used also for solving classification tasks with the aim to construct a classification rule allowing to assign a new observation to one of K ($K>2$) groups. In the situation $K>2$, however, it is unsuitable to consider the response in the form of a single variable with values in the set $\{1,2,\ldots,K\}$.

Therefore, a special PLS version combining dimensionality reduction with classification into $K>2$ groups. It has been denoted as PLS-DA or D-PLS to stress the discrimination (i.e, classification) context [16, 28]. The training p-dimensional observations are considered. The (multivariate) response is considered as a block of indicators, while the are only $K-1$ of them for K groups. A given observations, if belonging to the k-th group with $k \leq K-1$, has only the k-th coordinate of the response to be equal to 1 and the remaining coordinates are zero. If $k=K$, then all its $K-1$ coordinates are equal to 0. The resulting model remains to be again the standard linear regression model, where X plays the role of the matrix of regressors and Y represents the multivariate response with the total number of $K-1$ indicators.

The PLS-DA method searches for the optimal transform (linear combination) of regressors as well as responses so that the resulting latent variables allow the maximal possible separation among the K groups. To estimate the parameters of the model requires solving an optimization problem, which maximizes the covariance between the set of regressors and the set of responses. The resulting latent variables are predictive, i.e, able to discriminate among the groups in the optimal way. At the same time, the contribution of individual original variables to the construction of the classification rule has a clear interpretation.

Important properties of the PLS are common for the regression and classification version:

- The result of the computation depends to some extent to the choice of the algorithm
- A suitable number of latent variables are commonly found by a cross-validation, although it may have a tendency to overfitting.

Some special versions of the PLS have been proposed more recently, including PLS-EDA (PLS-enhanced discriminant analysis) or OPLS (orthogonal PLS), where the latter offers the same prediction ability as the standard PLS but improves the interpretation. Intensive attention has been paid to the study of assumptions under which the PLS yields better results compared to those obtained with a combination of the PCA with one of standard classifiers.

The PLS methodology resembles that of canonical correlation analysis, while the first maximizes the covariance but the latter is focuses on correlations. Their relationship was investigated by Sun L et al. [29], who showed their equivalence in a special case with orthonormalized PLS.

7 Hypothesis Testing

Hypothesis testing (e.g. a two-sample test) is often desirable for molecular genetic data to find a set of differentially expressed genes. Some recent tests for high-dimensional were overviewed in [16]. Here, we discuss briefly some important approaches to testing high-dimensional data. It is nevertheless useful to point out that testing may not be always the aim of the analysis (if the user prefers a classification rule from a test). Another drawback of simple testing by a repeated using of standard tests is their increase in the probability of type I error due to repeating testing. If there is a large number of samples n in the data, there is also a clear tendency for the power of the tests to increase and thus nearly every hypothesis test yields a significant result. Let us now review three important classes of tests for high-dimensional data.

One class includes tests based on regularization (shrinkage estimation), including the approach of [30]. It replaces all high-dimensional matrices (mainly the covariance matrices) by regularized counterparts and thus a shrinkage Hotelling test is based on a regularized version of the Mahalanobis distance.

Another class of tests of [31] represents a combination of testing with a linear dimensionality reduction. Tests based on linear scores or principal components (i.e, performed on results of LDA or PCA, respectively) are exact tests for normally distributed data. Using the theory of spherical distributions, the tests keep the significance level on the selected 5 % and follow exactly the t- or F-distribution if the variable selection based appropriately performed on the unsupervised data.

The most recent class of tests is based on interpoint distances. Tests based on a nonparametric combination of dependent interpoint distances are consistent and unbiased for high-dimensional data even without the assumption of normally distributed data [32, 33].

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In Memory of Jana Zvárová: a Project for a Comprehensive Assessment of the Clinical Effect of Specifically Selected Natural Remedies on the Treatment of Knee Osteoarthritis

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Abstract

Jana Zvárová had a lion's share in the founding of the Balneology Research Institute, a public research institute, in 2011. She played an important role in promoting the approach of Evidence Based Medicine and Information Based Medicine in the Czech balneology research. The aim was to establish a successor of the former state Balneological Research Institute, which was discontinued in 1992 without being replaced by another institution. Her scientific erudition has brought the elements of preclinical analysis and clinical evaluation into the scientific work of the Balneology Research Institute. The result was a scientific study not only of the extent of the positive effects but also of how natural remedies will improve the health state of the patient. In this contribution the project "The objective evaluation of the clinical effect of specifically selected natural remedies used for the treatment of knee osteoarthritis of the 2nd and 3rd degree" will be discussed as a tribute to Jana's influence. The used methodology was a fundamental innovation in balneology science and research. Unfortunately this project wasn´t approved by The Ministry of Education, Youth and Sports support programs. We will follow Jana Zvárová's approach in the future and will continue to try raising funds for the project.

Keywords

Evidence based; Balneology; Electronic health record; Clinical Study

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1 Introduction

We started working with Jana Zvárová in 2005. At that time, our colleague Petr Hanzlíček brought us to the EuroMISE Center of the Institute of Information Technology of the Czech Academy of Sciences. We were looking for partners to support us with the biostatistical evaluation of the project Objectification of the choice of the spa curative plan for hip arthrosis. Statistical analysis makes it is possible to determine the strength of the correlation between the type of curative plan and the therapeutic outcome. At the Euromise Center we met Jana Zvárová. She first expressed an unusual question: Why Evidence Based Medicine is not applied to spa treatment? Why does there not exist a successor institution of the state Balneological Research Institute, which was discontinued in 1992? Czech spas moved step by step out of the health services system, managed by the Ministry of Health of the Czech Republic. As a result balneology traditional healing is used nowadays only. Health insurance companies pay spa treatments without interest in the effectiveness of such treatment. The Czech Baths provided and provide actual healing rather than medical care based on Evidence Based Medicine (EBM). Jana agreed to cooperate and she had a lion's share in the founding of the Balneology Research Institute, a public research institute, in 2011.

To provide some insight in the project mentioned above and in what kind of curative plans are used in balneotherapy I give a short description. It concerned a study among 51 patients with 3rd degree coxarthrosis that underwent a comprehensive three-week lasting spa therapy. The basic version of the curative plan included: 6 times 30 min. - therapeutic gymnastics in the pool, 8 times 30 min. - individual curative gymnastics, 8 times 30 min. - hip joints magnetotherapy, 8 x peat wrap, 15 min, 42°C (every patient for 3 weeks, 2 to 3 times a week), further therapy (hydrotherapy, etc.). Another version of the treatment plan was also investigated. It was identical to the above curative plan with the exception of having carbonated baths instead of peat wraps. It was investigated whether the effects of

selected therapeutic procedures in the curative plan correlated with changes in the patient's state of health such as the difference between walking without support before and after the spa treatment. The analysis showed that there was a significant improvement in the curative plan group of 8 peat wraps. This was apparent from the strengthening of the majority of the attenuated muscle groups monitored and improvements in the magnitude of momentum. In the group without peat wrap, there was only minor improvement.

Our gratitude to Jana for her inspiration for the application of EBM in balneology will last. After the foundation of Balneology Research Institute in 2011, Jana was the Vice President of the Council for the entire period. She was the main architect of scientific work and helped us to obtain financial support for all our scientific research work. I worked closely with her on several important (and laborious) requests for subsidy. The last time (2016) it concerned financial support to put together an excellent team for the project "The objective evaluation of the clinical effect of selected natural remedies used for the treatment of knee osteoarthritis of the 2nd and 3rd degree."

2 Problem Description

Several EMA members participated in the preparation of this project. Main research manager L. Mankovecky of the Balneology Research Institute formulated the methodology of the clinical research on the basis of a systematic review. Osteoarthritis (OA) of the knee joint is one of the most common diseases. OA treatment involves several different approaches. In clinical practice, chronic pain is suppressed in the case of knee OA by analgesics and non-steroidal anti-inflammatory drugs (NSAIDs), while drugs that modify OA disease as well like intra-articular administration of both viscolubricants and corticosteroids are also used. The disadvantages of using these treatment modalities are, among other things, undesirable side effects and moreover it concerns treatment of symptoms only, not the disease itself. At the same time, potential stem cell applications or the use of biologic therapy are still very expensive and their effectiveness for the treatment of knee OA is still under investigation. As a last resort for severe 4th degree gonarthritis, the possibilities of radical surgery, partial osteotomy or complete replacement of the joints, are available. In addition to pharmacotherapy and the therapeutic approaches already mentioned, rehabilitation methods and spa treatments are also used.

Empirical experience shows that the application of spa treatment is also suitable for use in case of developing and / or progressive degenerative changes, i.e., the 2nd and 3rd degree of knee OA. In spite of the positive effect of natural remedies to relieve pain and improve the functionality and mobility of patients who are suffering from OA, the mechanisms of action of natural remedies have not yet been clearly elucidated. Therefore, in recent years, OA research has focused on determining the effect of biomarkers, including immunomarkers. At present, there is a lack of studies exploring the effects of natural remedies for the knee joint of OA patients. Very important is the monitoring of changes in the dynamics of the biomarkers already identified, with regard to their interaction with natural remedies.

Unfortunately the Ministry of Education, Youth and Sports rejected the request for support. We will try to continue with a simplified version of this project. In the next sections I will describe the initial project.

3 What is the Goal of the Project?

The aim of this project is to determine:

- Whether or not the selected natural remedies that are utilized for the therapy for gonarthritis of the 2nd and/or the 3rd degree will influence the metabolism of the subchondral bone whether selected natural remedies will affect the joint and/or the process of cartilage regeneration or, on the other hand, inhibit the process of the degeneration of the cartilage or

- Whether they will influence immunological processes that could trigger the degeneration of the cartilage and/or cause damage to the joint synovium.

An assessment of these processes will be carried out through monitoring of any quantitative changes that occur in the complex of selected biomarkers and that are also related to changes in the functional capacity and mobility of the affected joint(s), to pain symptoms and to the quality of the life of the person with knee OA. It is a comprehensive and, in terms of its approach, also a unique type of assessment, given the projected interdisciplinary project team.

4 Methods

This project offers a comprehensive interdisciplinary (physiotherapy, rehabilitation, balneology, physiology, anthropometrics, biomedicine, bioinformatics) perspective with the purpose of objectifying the clinical effect(s) of natural remedies of the spa treatment of osteoarthritis. The scope of this project is exclusively research to verify, define and also refine scientific theories. This research project focuses on the clinical evaluation of 6 peloids (peat or peat soil) and 6 healing natural mineral waters. The effect assessment will be done at two levels. First, the assessment of quantitative changes in a broader set of 20 selected biomarkers. Secondly the functional capacity and mobility of the affected joint, as well as the pain and quality of life of the proband will be assessed. The systematic search for clinical research articles that focused on the effects of natural remedies via the world's leading search sites Medline (PubMed), Scopus, Web of Science, Cochrane Library, and Google Scholar confirmed a number of similar global scale approaches with different levels of quality. So we had the benefit of knowing the latest results in this area. The choice of biomarkers and the way they were monitored will allow not only to ascertain the effects of

natural remedies but also to focus on the issue of how natural remedies work. Every natural remedy will be tested through a double-blind randomized study.

5 What Changes are Expected Due to the Project?

A comprehensive and multidisciplinary view to solve the examined problems, including support through international cooperation has a high potential to generate results that are comparable with the research outputs of prestigious foreign institutions. Additionally, this project opens a door for the creation of a unique international and interdisciplinary communication network for scientific fields in which there is a high priority for the creation of new jobs that are intended to support excellent young researchers.

6 In What Aspect is the Proposed Solution Actually Innovative?

Previous studies that focused on the treatment of gonarthritis by means of natural remedies always assessed individual criteria that correlated the treatment outcomes with either X-ray, CT, MRI or ultrasonography imaging but mostly, however, with the assessment of the subjective perception of pain and of the quality of life. None of the studies addressed the assessment of biochemical, immunological and functional criteria and the criterion of pain in quantitative terms. Previous research assesseds the role of individual anti-inflammatory biomarkers of immunopathological processes taking place in the knee joint, in the synovium and/or in the cartilage that characterize either bone metabolism, anabolism or catabolism. These were mainly descriptive studies, however, without any illumination of the principles that determine how the values of these markers vary in relation to the natural remedies that have been applied. Therefore, compared with previous studies our research is designed to enable, in accordance with the application of selected natural remedies, the monitoring of any changes within the entire complex of the defined biomarkers (biochemical and immunological) and their interaction in relation to changes in the functional parameters of mobility and in regard to pain perception. An objective evaluation of specific functional changes of mobility and agility, together with an emphasis on changes in stability, was only rarely utilized as a research topic. Also exceptional is the monitoring of changes within the complex of the selected biomarkers and of aspects of the quality of life 4 and 12 months subsequent to the experimental intervention. Such a detailed and comprehensive solutison of the objectification process in relation to the effects of natural remedies is therefore unique in this area of scientific research.

7 Conclusion

Within the EU Evidence Based Medicine (EBM) is increasingly promoted. At the 21st Annual Conference of the European Spa Association (ESPA), held on 26 May 2016, President Thierry Dubois introduced the pillars of his program. He said there was a need to support research with evidence-based approaches to the spa treatment.

In the Czech Republic, access to spa treatment, based on the recognition of traditional healing practices based on experience, gained over many decades, is still prevalent in the spa community. The ambition of the joint workforce of the Faculty Physical Education and Sport and the Balneology Research Institute is to promote the application of EBM in Czech and international spa practice and to give the Czech balneological research back a leading position in Europe. In practice, the only way is to introduce a clinical research methodology into the evaluation of the effects of natural remedies and to objectivize the evaluation of the effects of spa treatment.

As mentioned abtove, we intend to proceed with our project in a simplified scope and at considerably lower costs. In doing so, we want to preserve the main idea of this research, to promote Evidence Based Medicine in the Spa branch of medical services. We want to continue the journey that we have started with Prof. Jana Zvárová.

Decision Support Systems: Present and Future

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Abstract

Background: Information and communication technologies have become inevitable and an almost inseparable part of our lives. They have also penetrated many application areas including medicine.

Objectives: The paper demonstrates the importance of correctly understanding the terms data, information and knowledge that represent the core of decision support and decision making processes.

Methods: In the paper we describe the development of decision support systems from the first generation using a simple knowledge representation up to complex distributed solutions.

Results: Based on the purpose, we identify three major groups of systems, namely recommendation, decision support and decision making systems.

Conclusion: We summarize the development of decision support systems and estimate the future directions.

Keywords

Decision support system; Recommendation system; Knowledge; Information; eHealth

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1 Introduction

Healthcare is an information-intensive sector. Thanks to advanced technology, the number of devices connected directly to computers is continuously growing. Consequently, the volume of collected data is increasing tremendously. These new technologies are speeding up the exchange and use of data, information and knowledge, and are eliminating geographical and time barriers. These processes highly accelerated medical informatics development. Today's healthcare environments use electronic health records that are shared between computer systems and may be distributed over many locations and between organizations in order to provide information to internal users, to payers, and to respond to external requests. With increasing mobility of populations, patient data is accumulated in different places, but it needs to be accessible in an organized manner at national and even global scale. Large amounts of information may be accessed via remote workstations and complex networks supporting one or more organizations, and potentially this may happen within a national information infrastructure. The key terms in this context are data, information and knowledge [1], and decision support.

2 Data, Information and Knowledge

Data represents images of the real world in abstract sets. With the aid of symbols taken from such sets, data reflects different aspects of real objects or processes taking place in the real world. Mostly data are defined as facts or observations. Data results from a process of measurement or observation. Often it is obtained as output from devices converting physical variables into abstract symbols. Such data is further processed by humans or machines. Human data processing embraces a large range of options, from the simplest instinctive response to applications of most complex inductive or deductive scientific methods. Data-processing machines also represent a wide variety of options, from simple punching or magnetic-recording devices to the most sophisticated computers or robots.

The word *information* is often used without carefully distinguishing between different meanings it has taken on during its history. Generally, it refers to a finding or findings concerning facts, events, things, people, thoughts or notions, that is, a certain reflection of real or abstract objects or processes. It usually consists of its syntactic (structure), semantic (meaning), and pragmatic (goal) components. Therefore information can be defined as data that has been

transformed into a meaningful and useful form for specific human beings. Data whose origin is completely unknown to us can hardly bring any information. We have to "understand" the data. An idea of where and under what conditions the data was generated is an important context of each message, and it has to be taken into account when we establish the information content of a message. Data sources thus become important components of what we are going to call information sources below.

The notion of *knowledge* is related to that of language-ontology; within this model, the notion of knowledge can be treated in a more specific sense. This model is based on the assumption that there is the universe (ontology) consisting of objects which have certain properties and among which certain relations exist. Further we assume that there exists language in which ontology can be described. The notion of knowledge is mainly used intuitively. Within the model of language-ontology, its meaning can be defined in a more specific way. Knowledge will be understood as a true proposition concerning the ontology, formulated in the underlying language.

There are different kinds of knowledge. *Analytical knowledge* comprises those true propositions the validity of which can be derived from semantic postulates using purely logical means. It does not depend on the ontology, i.e., is valid in each and every one. *Synthetic knowledge* is knowledge, which is not true in every ontology and its validity must be decided on the basis of an experiment. Basic examples of synthetic knowledge include statements whose validity has been confirmed by direct observations. Such items of synthetic knowledge are called facts.

In practical applications we can find a large variety of systems that are described by their authors as expert systems, knowledge-based systems, or decision support systems. In fact however, some of them do not satisfy the basic characteristics of these systems. Some belong to classification or prediction systems, which are usually data intensive systems. Decision support systems can be characterized as knowledge intensive systems.

3 Present and Future of Decision Support

In the past, decision support systems were mostly used in narrow special applications and the users although not being top experts in the area had very good knowledge of it. The first generation of decision support systems was most frequently represented by simple, rule-based diagnostic system. From the programming technology point of view, they represented quite a specific class of decision support systems based typically on the inference net approach. Unfortunately, the simple first generation systems were not sophisticated enough to solve complex tasks in a wider problem area, most of all because they were limited to exploitation of the surface (shallow) knowledge, and the knowledge representation (based on the inference net, only) led to cumbersome behaviour of the system in the case the volume of relevant knowledge exceeded a certain threshold (if there were more than, let's say, 500 rules to be taken into account).

The advanced decision support system technology explored – besides the original idea of propagating uncertainty in an inference network – additional AI techniques which significantly enhanced the system capabilities. Specific methods and techniques have been developed to overcome the shortcomings of simple decision support systems mentioned above, e.g.:

• Different context/control links (having the nature of meta-rules) have been introduced to ensure both the common sense ordering of questions as well as the efficient cutting-off of irrelevant parts of knowledge bases in the early stages of a consultation run.

• Various blackboard control structures enable to split the knowledge into more knowledge bases (knowledge sources) and to cope with this set of knowledge bases in parallel. The WHEN-THEN rules are applied on the blackboard level to control the exploitation of the knowledge base set. Even a very simple blackboard control adds a lot of valuable features to the system. It enables, e.g., solving of monitoring tasks, problems requiring non-monotonic reasoning, zooming of attention, etc.

• Combination of different knowledge representation schemes has been performed with the stress to enable representation of causal, deep knowledge. It is possible to combine the inference net with the semantic/taxonomy net, with a subsystem for qualitative simulation, etc.

All the extensions and enhancements of "classical" rule-based diagnostic decision support systems described above represented steps towards more complex systems. The second-generation solutions considered separate knowledge-based modules of diverse nature, each being equipped by a specific inference algorithms. These modules were expected to be integrated by precisely specified, fixed links and relationships. The second generation decision support systems were able e.g. to integrate "classical" expert systems with neural net emulators, genetic algorithm based modules and databases. The information transfer among the modules enabling the system integration was ensured by a *centralized integration program* running in the integration framework.

Both the first and second generation decision support systems, even being significantly enhanced by very specific methods, operated very efficiently, but usually only in a narrow field of expertise. The next step in the development was connected with the rise of Internet and local as well as wide area networks allowing distributed solutions. Distributed problem solving and multi-agent architectures have become attractive for many application areas that are naturally distributed.

The multi-agent technology has already proven that it is suitable for creating an open, flexible environment able to integrate software pieces of diverse nature written in different languages and running on different types of computers.

It enables to design, develop and implement a comparatively open multi-agent environment suitable for efficiently creating complex knowledge-based or decision support systems. Such an environment is able to integrate geographically distributed knowledge sources or problem solving units. Multi-agent systems have useful properties, such as parallelism, robustness, and scalability. Therefore they are applicable in many domains which cannot be handled by centralized systems. In particular, they are well suited for domains which require, for example, resolution of interest and goal conflicts, integration of multiple knowledge sources and other resources, time-bounded processing of very large data sets, or on-line interpretation of data arising in different geographical locations.

Modern health care is highly specialized. Complex examination of a single patient involves many expert consultations and laboratory tests. Medical knowledge, examinations and treatment are distributed functionally, geographically, and also temporally. There is a need for a reliable and consistent information flow among all participating subjects with the aim to satisfy the global goal – improved health of a patient. Of course, the necessary information flow is not predictable in extent and structure, but it develops and changes in time due to new knowledge and reactions. To satisfy these requirements and provide adequate decision support, the use of flexible intelligent software support is becoming increasingly desirable. Distributed problem solving and agent technology offer efficient and natural solutions, because they correspond to the main properties of the medical domain, namely distribution of information, problem-solving capabilities, resources, and responsibilities, decision-making with incomplete information, and iterative refinement of plans.

With the booming of information and communication technologies (ICT) and all smart devices, various applications appear having the characteristics of decision support. Health care is a typical example of an area in which the number of various applications is extremely high. However, we have to point out that only a fraction of these applications was verified by complex tests and satisfies requirements laid on software used in the medical environment. Therefore we have to distinguish these systems from several points of view: how they use knowledge; what their purpose is; who the primary users are.

Pharow P, et al. [2] discussed the main differences between three larger groups of systems that differ in the way how they use knowledge and information for decision support and decision making.

In summary, the three groups are:

1. Systems and devices that can be summarized as *recommendation and suggestion systems*, which are systems and devices we can find, for example, in the area of well-being and fitness, and which serve mainly for informing the users / clients about their health status;

2. *Decision support systems* – which serve as guidance for professionals and experienced users, like chronic patients on the one hand and active athletes on the other;

3. *Decision making systems* – which contains systems and devices that are directly linked with an actuator part influencing patient's health, by that way making decisions automatically or at least semi-automatically depending on, e.g., the severity of recorded and analyzed vital signs.

Additionally it is the human factor that is most significant, as the first two groups of applications require, and rely on, the interaction of a human being with a system, a machine, a device or an application. These two groups already represent, and will represent even more frequently in the future, the majority of applications directly used by patients.

The aforementioned division of systems is not the only one. We can differentiate the applications by the purpose into the following major groups. The first group aimed at clinical research uses the collected data in controlled manner. The application might be a pure software app or a combination of a medical device and software. The data are interpreted and verified by medical experts. The second group utilizing pure mobile applications developed in the frame of clinical research and transferred to routine use collects data from the patients. The data are sent for interpretation to a medical centre. The third group is aimed at the general population. The applications can be either mobile apps in smart phones or applications collecting data from, for example, a fitness wristband. Regarding the output of the applications, the first two groups might represent decision support systems, while the last group represents a recommendation system [2].

4 Conclusion

In the paper we tried to describe briefly the most important issues connected with decision support in medicine. Data, information and knowledge represent the core of decision making processes. During the last decades, decision support systems changed extremely from applications for narrow groups of specialists to more widely used applications. At the same time, it proved that the first generation systems were able to deliver expert decisions in a very narrow area of expertise, but failed outside the area and were not able to represent more complex knowledge. The second generation came up with new types of control structures and knowledge representation schemes. With the introduction of computer networks, distributed problem solving systems and successively multi-agent systems appeared and proved to be more flexible and efficient for tasks that are naturally distributed. Thanks to the availability of ICT, the systems are more widely spread and used. However, it is necessary to be aware of differences between various applications: they range from untested and unverified systems that can be only considered recommendation systems over decision support systems to decision making systems while both latter categories must be tested and verified for medical use.

The future development is clearly connected with advanced technologies, including utilization of the Internet of Things.

Decision support and decision making based on applying advanced ICT in terms of micro and nano technology devices like sensors, actuators, and respective (wireless) body area networks (WBAN) will advance in the future.

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Medical Informatics Education - Past, Today and Future

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Abstract

The development of medical informatics goes back to the second half of the twentieth century with the start of the automation of processes. Medical informatics education plays an important role in the education of health care providers and medical providers. Education in medical informatics is not only important for medical students but also for other medical staff at all professional levels of education. Integrating medical Informatics into the full spectrum of medical education is a vital step required for the understanding and practice of modern medicine. There are curricula in the field of medical informatics at many universities in Europe. Great roles in this field had the International Medical Informatics Association (IMIA) and – the European Federation for Medical Informatics (EFMI). Working groups of IMIA and EFMI defined and recommended concepts and methodologies of education for medical informatics on three levels. Generally in all European countries medical education at universities is organized on the basis of the Bologna concept, which has improved the quality of teaching process in plenty matters, but it has brought a big number of highly educated staff, that are younger than average, but also have average level of knowledge. Basically, the Bologna system has brought averageness we tried to escape from. With the introduction of the Bologna process in Bosnia and Herzegovina and other countries, a new process is being introduced which introduces a new curriculum, a greater number of subjects, a complemented systematization of knowledge and the need to correct past attitudes. Since the curriculum of medical informatics varies between countries and universities and faculties in the country, it is necessary to take steps towards the unification of the curriculum at the international level. Aim of the article is to show the status of medical informatics education in Bosnia and Herzegovina and Europe.

Keywords

Medical informatics; Education; Curricula

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1 Introduction

The development of medical informatics goes back to the second half of the twentieth century with the start of automation of processes [1, 2]. The need for additional education of health professionals was felt after the first applications of electronic data manipulation [3, 4]. For physicians in primary health care and in clinics, in order to perform their duties in a high quality manner, must be up to date with the latest accomplishments in medicine and health. Several different schools of Medical informatics were established in the world: by Morris Collen in USA, by William Abbott in UK, by Francois Gremy in France, by Peter Leo Reichertz in Germany, by Gjuro Dezelic in former Yugoslavia, etc. [1, 2]. Since the 60's the development of information technologies has had a quantitative and qualitative growth especially in diagnostics and therapy, and health workers had to follow that [3]. A great role in this field had the International Medical Informatics Association (IMIA) and – the European Federation for Medical Informatics (EFMI). Working groups of IMIA and EFMI recommended and defined concepts and methodologies of education for medical informatics on three levels [5].

In Europe, EFMI is the leading organization in medical informatics and represents 32 countries. EFMI was founded in 1976 [5].

The national associations/societies for Medical Informatics in Europe and other parts of the world, linked by IMIA and its branch offices, are engaged in the organization of international and regional gatherings and congresses, where experiences and strategies are exchanged. Also, some medical informatics societies have launched journals dealing with themes in the domain of medical informatics [1].

2 Medical Informatics – Educational Concepts

Medical informatics education plays an important role in the education of health care providers and medical providers [5]. Education in medical informatics is not only important for medical students but also for other medical staff at all professional levels of education. The advent of healthcare reforms and the rapid application of new technologies have resulted in a paradigm shift in medical practice. Integrating medical informatics into the full spectrum of medical education is a vital step required for the understanding and practice of modern medicine [1]. There are curricula in the field of medical informatics at many universities in Europe. Bachelor's Degree Program in Medical Informatics can be attended at 14 universities in Germany following the concept of medical informatics education proposed by Peter Leo Reichertz who proposed the term Medical Informatics in the scientific literature in 1972. Specialization provides graduates who can develop IT solutions. These specializations are not part of curricula of medical faculties or related faculties, but an independent study that is primarily oriented to medical informatics as a major study program. They can develop medical imaging techniques as well as diagnostic procedures and organize the management of patients' data. For this purpose, the basics of computer science are taught. These include, for example, programming, mathematics and statistics, algorithms and data structures or the development of databases [2].

The competence for the development of customized programs, software engineering, is also taught. Basic education also includes fundamental medical knowledge in the most important areas, and diagnostic and therapy systems [2].

Modern information technologies play a major role in the work of doctors after the completion of medical studies. Physicians are faced with a large amount of information that needs to be processed. Based on such information, decisions need to be taken that are essential for the further treatment of patients. The ease with which doctors can retrieve the relevant information they will use to treat patients plays an important part in everyday practice (Table 1).

3 The Bologna Process and Medical Informatics

The Bologna process introduces standards and norms that include the duration of study and weekly workload in teaching and overall work needed to master some skills, so that there is no arbitrariness. Under this process, the duration of study is divided into three clearly defined segments: undergraduate, postgraduate and doctoral graduate studies, which have a precisely defined duration [4].

The Bologna declaration has improved the quality of the teaching process in plenty matters, but it has brought a big number of highly educated staff, that are younger than average, but also have an average level of knowledge. Basically, the Bologna system has brought averageness we tried to escape from. The solution of this can be in setting higher standards and better outcomes of education by using new available technologies that can contribute to higher quality of teaching [6, 7, 8, 9, 10, 11]. These technologies include distance learning, online teaching, and online student testing. This implies creating a set of items that covers all areas of a subject that students answer and then receive immediately the response whether the answer is correct or not. The student can immediately see the text of the textbook relating to the given question. Although this method is efficient, it requires a great effort from the teaching staff that needs to create a large number of questions and answers that students have to manage. The Bologna process has brought a new curriculum, contributing to the engagement of a greater number of teaching staff and a new way of presenting knowledge to the student, who more acts in the role of a passive observer in the education process [6]. We don't expect an instant solution of the aforementioned problems, but in the long term, this process could lead us to increasing quality, which would bring us closer to modern developed countries and their education systems. We shouldn't forget that knowledge is the most powerful weapon in the world, and its use is the path to prosperity and progress in community.

Bosnia and Herzegovina signed the Bologna declaration on 18 September 2003 in the light of this new approach to university education, and the process of joining the European Union. In order to investigate the effects of the Bologna declaration on the education process, Masic et al. set the following aims for research [7].

- To determine the current level of knowledge among medical students at the Medical Faculty of the University of Sarajevo after the declaration was implemented in comparison to pre-Bologna students.
- To determine the level of knowledge among medical students before their enrolment at the faculty compared with pre-Bologna students.
- To find out students' opinion on their needs for further education.

Conclusion of research was that a) Continuous quality of education must be assured (use of internal and external evaluation); b) Medical curriculum needs to be adjusted with the curricula used in EU member states where quality assurance is significantly implemented; c) University teachers and staff must be evaluated regularly; e) Medical students must be involved in all the reform processes; f) Volume and content of the practical medical education must be improved; g) Library services must be improved and educational facilities must be equipped for use of information technology [8].

After the Bologna declaration, medical informatics has become an integral part of all curricula in the field of health studies at medical and related faculties. However, there is no single program for all faculties of individual universities, both at national and international levels. Interesting differences exist both within and between countries and programs with regard to curricula structures and expected learning outcomes. Several initiatives have been launched in the last years to define some standardized content of curricula, aiming at developing sample medical informatics curricula [6, 7, 8, 9].

4 Medical Informatics Curricula (Example of Bosnia and Herzegovina)

Many universities are organizing teaching programs for medical students in medical informatics. The start of the study in medical informatics as part of curricula for medical students is not the same in all Universities. One prefers to start medical informatics in the first or second year of study while the other prefers teaching medical informatics in the final year.

Medical informatics is being studied at several faculties within a university, e.g., Faculty of Medicine, Faculty of Dental Medicine (Stomatology), Faculty of Pharmacy, and Faculty of health studies (bachelor program). Master studies and doctoral studies also include curricula in the field of medical informatics. Here is the list of State Faculties at Universities in Bosnia and Herzegovina where medical informatics is studied (Table 1).

In Bosnia and Herzegovina we encounter a great variety of curricula between universities as well as at different faculties of the same university. First of all, there is a difference in the title of the subject. The most commonly used title of the subject is medical informatics. However, the curricula at the Sarajevo University's Faculty of Health Studies, at the Mostar University's Faculty of Health Studies, and at the Faculty of Medicine of the University of Tuzla combine medical informatics and statistics as one subject. The University of Mostar on the other hand combines the methodology of scientific work and biomedical information technology as one teaching subject. The other variants of the name of the subject are: Informatics; Informatics in healthcare; scientific methodology and medical informatics; Methodology of scientific work and biomedical information technology; Informatics in medicine; and Informatics with medical statistics. The total number of earned ETCS points as well as the number of practical lessons and lectures varies considerably among faculties (Table 1).

5 Medical Informatics Education Today

Informatics education begins in elementary school so that students at the moment they start their study at the university have already some basic knowledge. Further education of information technologies during studies at biomedical faculties is aimed at a better management of medical information. Since students are confronted with a large quantity of information that they have to deal with at the end of their studies, medical informatics plays an increasingly important role. The outcomes of learning after education in medical computing therefore make up a significant part of the skills taught during the studies at biomedicine faculties. These skills will greatly assist future medical workers in treating patients, e.g., in solving current problems and in the process of medical decision making.

Many older medical workers are faced with the need to use computers to enter and process data and to create various statistical reports, although they did not have the opportunity to have formal education in medical informatics during their studies. Young healthcare professionals who pass education in medical informatics during the course of study can help in such cases to overcome these obstacles.

The time to begin education in medical informatics at universities is still not precisely defined. Most faculties prefer to start education in the first year of study so that the acquired skills can be applied by students during the studies of the biomedical faculty. On the other hand, a smaller number of biomedical faculties believe that some of the finishing years are ideal for education in medical informatics, because only then do students master medical knowledge to be processed using a computer.

Medical informatics courses can also be divided into two parts where the basic skills in medical informatics would be taught in the first years of study and applied medical informatics in the last year of the study after obtaining the necessary medical knowledge [12, 13, 14, 15]. This applies in particular to aspects of medical informatics such as medical decision-making, classification systems, health information systems, and similar issues. This concept acknowledges that only people with profound medical knowledge can fully understand those issues. Faculties where medical informatics is studied are Faculty of Medicine, Pharmacy, Health Care, and Dentistry.

The development of modern technology and the Internet have enabled the explosive growth of distance learning (DL) [14, 15, 16]. DL is a process in education that focuses on educating students who are not physically present in the traditional classrooms or the student's campus. It is described as a process where the source of information is separated from the students in space and time [10]. Due to a legal obstacle, it is not possible in Bosnia and Herzegovina to organize distance learning because students must be present in the class. DL can still be used for online learning so that students can get assignments from teaching staff and send documents containing solutions to task sets (seminar papers, presentations and the like).

Universities and other educational institutions as well as the government share responsibility for guaranteeing high standards and quality of medical education.

Table 1. The names of subject, semester, works hours and etc. points at state universities in Bosnia and Herzegovina.

University and Faculty	Name of Subject	Semester	Total work Hours (L+P)	ETCS
Sarajevo University				
Faculty of Pharmacy	Pharmaceutical informatics	IX	30+30	4
Faculty of Medicine: two different studies:		IV	15+15	2
• In Bosnian	Medical Informatics	XI	15+30	2
• In English	Medical Informatics	IV	20+10	2
Faculty of Dentistry	Informatics	IV	40+15	6
Faculty of Health Studies (Bachelor program)	Introduction to health statistics and informatics	II	30+30	5
Tuzla University				
Faculty of Medicine	Informatics with Medical Statistics	IV	40+15	4
Department of Health Study of Faculty of Medicine (Bachelor program)	Medical informatics	IV	30+15	5
University of Zenica				
Faculty of Medicine	Medical informatics	III	30+15	3.5
Faculty of Health (Bachelor program)	Medical informatics	II	30+15	2
University of Bihać				
High School of Health (Bachelor program)	Informatics in Healthcare	I	30+30	4
East Sarajevo University				
Faculty of Medicine - Foča	Informatics in Medicine	II	15+15	1
Faculty of Health (Bachelor program)	Informatics in Healthcare	I	15+30	3
University of Mostar				
Faculty of Medicine	Scientific methodology and medical informatics	I	22+70	9
Faculty of Health Studies (Bachelor program)	Health information system and medical statistics	I	30+60	10
Faculty of Pharmacy	Methodology of scientific work and biomedical information technology	IX	30+15	3.5

The aim of medical education is to educate doctors and other health care professionals who are entitled to practice their profession with no restrictions, based on what they learned [3, 5]. The first professional degree means completing a curriculum which qualifies the student for a range of different choices in his/her career, including the treatment of the diseased, public health service, clinical and basic research, or further medical education. One of the significant approaches to education is learning by doing. Any further career choice requires additional education apart from that leading to the first professional degree [4, 5]. The university is responsible for creating an academic environment where learning and research can progress in an optimal manner. To improve medical knowledge and to provide the best quality of health protection, active medical research as such has to be carried out under academic conditions in order to meet the highest medical standards [3].

Teaching of medical informatics should be a collaborative effort to expose students to a variety of medical information management applications. The medical informatics educational model has a modular format so that students can work with a variety of realistic situations and become enthusiastic users of computer-based medical information systems. All faculties should introduce appropriate concepts and systems, and engage faculty staff to guide students in the

use of medical information systems. What should be integrated into the required curriculum is a matter of decision. A basic medical education principle includes education leading to the first professional degree (the title of the General Practitioner or GP), clinical education as preparation for general medical practice or specialty, and obligatory continuous, life-long education of each doctor.

The quality of the teaching/learning process depends mainly on infrastructure that includes an optimal teaching space, personnel and equipment in accordance with existing standards and norms at the cantonal or entity level at universities, which are required to adequately implement the educational curriculum for students from first to sixth year based on the Bologna concept. Such infrastructure needs adequate funding [12, 16].

6 Perspectives for Future Development of Medical Informatics

In the future, the medical informatics curriculum should be standardized to overcome the apparent difference in the programs. There are also differences in the number of ETCS points earned at some faculties. It is necessary to determine which areas of medical informatics are required for certain medical workers. To advance international cooperation and dissemination of information in medical informatics on a European basis is essential to achieve these tasks. In the future, high standards in the application of medical informatics should be promoted. Further development of medical informatics as well as education in medical informatics is an important factor for improving the level of teaching at the biomedicine faculties. High standards in education in medical informatics should been encouraged through standardization and taking into account the emerging IT technologies.

For education in medical informatics the following kinds of learning outcomes can be identified. They assure that graduates from such programs know at least the basics of those related biomedical and health informatics disciplines and to give various programs the flexibility to focus on one or more of those overlapping areas such as biomedical engineering, medical information sciences, molecular biology or nano-sciences, depending on the cultural, scientific and technical context of the institution [9].

Distance learning in medicine has impact on telemedicine and practicing medicine as well. Basic skills at the use of computers and networks must be a part of all future medical curricula. The impact of technical equipment on the relation between patient and doctor must be understood, because the situation where the diagnosis based on live voice or picture is different from a normal doctor-patient contact [12].

E-Learning, by definition, is using electronic learning aids which in our case may be a computer, PAD device or smartphone. As an integral part of E-Learning, distance learning stands out. Along with favoring knowledge as the most important global resource for the future, in the last decade extensive work has been performed on improvement and expansion of all forms of electronic support of the educational process [15].

Online tests and quizzes are one of the aspects of distance learning that are based on student interaction with the system. The system has stored the correct answers to these questions and explanations of the correct answers. When a student answers all questions, he/she can immediately see where a mistake is made and can take a second test until all the answers are correct. Additional statements explain why the answer is correct or not [12]. Distance learning should ensure high educational standards to students and teaching staff, and can help medical staff to develop "Lifelong learning way of life" [13, 15].

Managing a medical database should be a very important skill of medical workers in future. A medical database enables doctors to have better insight into the success of the treatment of individual patients and to determine whether certain methods of treatment are better than other ones. A comprehensive database enables us to make matches between any two or more groups of patients. A medical record is an important set of data that is designed to store information of all the events related to a specific patient and facilitate later data retrieval [1, 14]. Another important function of medical records is its use to evaluate diagnostic procedures or the outcome of some therapeutic and surgical procedures. Even with the help of medical records, these goals cannot be easily achieved. Old fashioned paper medical records that keep all of one patient's files in one folder (envelope) represent the traditional way of data collecting [2].

Nomenclatures and classifications are an essential part of scientific methodology in the health care. The existing state of the nomenclature of healthcare activities enables the optimal application of computer technology in processing and retrieval of medical data or information [2]. In the future, emphasis should be put on understanding and processing of data based on the use of medical classifications. Another more modern way of keeping patient records is a computer database that uses a medical classification such as the International Classification of Diseases, Injuries and Causes of Death (ICD). Now, it is possible to search the patient record more rapidly, but a patient can only access this data while he is in the physician's office. Medical records that form an integral part of information systems of individual countries are easy and comprehensive medical record keeping software for maintaining ones family's medical history. This way, a medical record can even better utilize ICD classification because there is more relevant information that is necessary to code specific disorders [2].

Forming interdisciplinary studies at universities will bring together medical professionals and information technology specialists who will educate a staff with knowledge in both

areas and so better respond to the needs of healthcare institutions. Such curricula are already normal in Germany, Austria and Switzerland and should be included in all university curricula.

7 Conclusion

Bologna's model of education at biomedical faculties in Bosnia and Herzegovina, since its introduction into practice 15 years ago, has not lead to the unique curriculum for most of the subjects, including the subject of medical informatics. The most integral syllabus of medical informatics, mostly in accordance with the recommendations of IMIA and EFMI, was introduced by the Sarajevo Medical Faculty in 1992. Unfortunately, the changes and amendments in the curricula resulted in the reduction and loss of the medical informatics subject in terms of teaching hours in theoretical and practical courses in individual study fields, as happened during the last 15 years in four fields of study programs. Students studying according the old system have the right to complete their studies by 2020 according to the program they started to study, and since 2002, the Bologna model controls the process. Since 2014, there has been a study of medicine in English. Furthermore, at some faculties, the fund of teaching hours for medical informatics was reduced, and sometimes the subject was even excluded from the syllabus. Medical informatics as a scientific and academic discipline has a great impact even prior to the modern era of information technologies. But, especially since it is becoming increasingly important in every day's modern medicine, where the application of information technologies has been rooted as the basis for all three levels of health protection in diagnostics and therapy through electronic documentation, management, clinical decision-making using software solutions and expert systems, etc. The use of information technologies has altered the science-research world. Modern science so without a database, would probably make no sense. Medical professionals are confronted by data processing in all spheres of activities using multiple software solutions for their everyday work.

The Bologna process in Bosnia and Herzegovina has minimized the importance of medical informatics and has also led the academic community to a very unfavorable position. While aiming at improving the quality of education itself, improving the level of quality of graduated doctors and getting extraordinary medical professionals, there is just a gain in quantity, neglecting quality. Reform is necessary in many segments, and it includes education in the field of medical informatics for all three levels of studies. Medical informatics should be perceived as essential in the digital world of modern medicine.

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Future Prospects of Health Informatics Summarized from the Special Issue 'Women in Health Informatics' to the Memory of Professor Jana Zvárová

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Abstract

This paper summarizes the future prospects of health informatics as seen by the authors of the Special Issue 'Women in Health Informatics'. The prospects are focused on health informatics important themes like patient-centered care and patient empowerment, data, secondary use of data, big data, security of data, Internet and emerging technologies, electronic health records, health informatics education, evaluation, social aspects of health information systems and legal and standardization issues.

Keywords

Medical informatics; Health informatics; Healthcare informatics; eHealth; Data

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1 Introduction

The Special Issue on Women in Health Informatics was initiated and planned with Professor Jana Zvárová. We three editors, Jana, Pirkko and Diane, worked intensively together in planning the issue, in inviting people to contribute and in reviewing their submissions. Jana was very happy and enthusiastic that we had been successful to invite so many distinguished colleagues to provide their stories and share their experiences on their career development in the health and biomedical informatics domain. We all felt that we had found with this Special Issue a valuable way to allow the voice of women and to highlight the achievements on women in the very challenging and multidisciplinary field of health informatics.

After the decease of Professor Jana Zvárová, it was very clear to us, Pirkko and Diane, that we continue, we finalize the work started. The Special Issue [1], published in November 2017, has two purposes: It is a memorial to Professor Zvárová, and her EUROMISE work, but also a tribute to the women, who have provided their career stories, all written in their own voices, more than a dozen exceptional women from around the globe, who have worked over the decades in bioinformatics, health informatics and digital health. Each paper also provides a view of the health informatics work that has been undertaken in their own country, problems encountered and insights into where health informatics may be seen to be heading in the future.

In this paper, we summarize the major findings of future prospects of health informatics as presented by the women in their career stories [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16]. These prospects reflect the various situations and backgrounds of women working as research scientists in this field. The prospects have been collected by walking-through all the women's articles and by condensing the findings. These prospects also devise the visions that are paving the way to the future of health informatics.

2 Future of Health Informatics – Major Issues Raised by Professional Women

Future will be the patient-centered; healthcare will be a process that crosses institutional and professional boundaries and cross-institutional eHealth architectures and infrastructures will continue to grow and support real patient-centered care and patient empowerment. Medical informatics has focused much by far on how to support doctors, nurses and other health care professionals in their work. But ultimately, it is the patient who has to decide what to do next. It is recognized that one of the key approaches to managing the spiraling costs of healthcare and of improving

outcomes is to empower citizens, who after all represent the greatest single underutilized resource, and encourage them to take responsibility for managing their own healthcare. This involves moving away from healthcare systems which are focused primarily on treating illness to ones which are focused on promoting health and well-being. Already today, patients are better informed than ever before, and they have demands for valid and trusted online health information which in turn means improvements in quality standardization and accessibility of tools like the HONcode.

Another important issue in the future and, already today, is the data. The current trends with all available data are: Clinical research is going towards personalized and precision medicine, health care providers are eager to measure the effect of their actions and to build a learning health care system, and data science is the new buzzword in computer science albeit not clearly distinguishable from conventional statistical methods for data mining. We need methods, tools and infrastructures to support data-driven medical care and biomedical research. The future health and wellness information systems need to take not only the biomedical and clinical data of a patient into account but also patient generated data on daily activities, patient preferences, and environmental context for an individualized decision that really meets the patients' expectations, values and needs. Currently, these soft factors for medical decision support are not sufficiently understood and researched in all dimensions. Data access, availability and shareable use should not be seen as a threat to professional practice or data-subject preferences, but should be handled sensitively and openly. Informed use will ultimately be beneficial and holistic records, right-sourced and evidence-based, will support population well-being.

With data an important issue is the secondary use of clinical data to support research and health care practice. There is so much patient data available now in an electronic format that offer tremendous opportunities for precision medicine, decision support, or new scientific insights. Also reuse of routinely collected data, e.g. for calculating quality indicators, is needed to obtain and provide new knowledge without additional data collection. To be able to use all the available data from electronic health record, legal regulation is necessary and more research is needed on natural language processing, terminological systems and information models that are essential to standardize and structure routinely collected data.

The current hot topics in health informatics, such as big data, self-management of health and personalized or precision medicine need to be integrated with clinical research and large collaborative research projects together with medical departments and computer science departments. The technical infrastructures and processes, as well as Internet, Internet of Things (IoT) and social media provide huge volumes of interinstitutional and personal health and wellness data. The future is in the data.

We also need to concentrate on the use of enabling technologies in patient safety, process engineering, change management, human factors, stress management, and clinical point of care initiatives such as adherence and emphasis on patient-centric care. With the current enabling technologies and more recent analytic tools such as telemedicine, visualization, robotics, and machine learning that have become available, the field of health informatics can expect exponential growth in the use of technology to transform healthcare for the citizens of the world. The evolution of electronic health records and connectivity has also led to increased efforts to realize a vision of a data-driven national learning healthcare system to improve clinical knowledge and practice.

Theory-based development and evaluation of interventions are needed to understand the mechanisms behind these systems and to contribute to identifying the active ingredients of successful interventions. To obtain explicit evidence we need to perform more scientifically rigorous evaluation studies that show that the systems developed and used are acceptable, safe and effective and support health professionals in their clinical tasks as well as patients and citizens in managing their health and wellness. We also need to pay more attention to the design and implementation methods of health information systems in order to have predictably acceptable, safe and effective systems for user environments

All these future visions and developments with data and technologies emphasize that health informatics terminology should be standardized at the international level. We should achieve shared understandings on concepts, terms and processes to be able to use them in the same meaning in the global world. And, it is important to improve the legal practices, e.g. the medical informatics associations should insist on legal and ethical aspects of all activities dealing with information and communication technology in medicine and healthcare.

Medical informatics education is an important issue – it should be part of education of all the health professionals as the end-users of information technology in healthcare, and it should be properly located in their curriculum. New educational programs should support this, e.g. by offering part-time studies or online-based studies. Education should also cover more experts from non-technical backgrounds, such as a medical or nursing background, or with a background in quality management, risk management or process management, field of medical informatics. Medical informaticians should be able to act as a bridge between the two sides, but a little bit closer to medical, health care side - at the source of health information, with health professionals, and to understand their information needs.

3 Summary and Conclusion

All women [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16], who have provided their personal health informatics story to

this special issue [1] have had the privilege to know Professor Zvárová, and to learn and to work with her. With these stories, each of us wants to pay tribute to, and remember, the achievements of Jana, as a professor, as a colleague and as a friend. These stories by qualified health informatics women also highlight Jana's influence on the health and bioinformatics as scientific disciplines and on the careers of all of us.

To summarize, the major challenge of medical informatics in the future will not only be to provide new methods for data analytics but to provide solutions that medical research results are available for use in patient care and for the patient itself. And, the health informatics community needs to find ways to build data models to systematically extract and link data along the continuum of care including their contexts and deliver the results according to research agendas that are driven by patient needs. These achievements lead to patient-centrality and a learning health system, where patients are involved in their health, are coached and motivated by clinical decision support, report outcome data, receive decision support, make shared decisions with their providers, and contribute to the body of evidence about treatment effectiveness, which could be mined by machine learning methods.

4 Acknowledgements

On behalf of all the women authors, I want to acknowledge Professor Jana Zvárová, for her initiative on this theme for the Special Issue, for her support, mentorship and collegiality throughout our careers, and her warm friendship. I also want to acknowledge Dr Diane Whitehouse, the other editor of the Special Issue, for excellent collaboration, both of us, Diane and me, want to acknowledge all these qualified women who have provided their stories, opened their career development and shared it with us all.

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Contemporary Developments in Digital Health: An On-Going Conversation with Professor Jana Zvárová

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Abstract

In the context of the 4 May 2018 Jana Zvárová Memorial Conference, this short article introduces my association with Professor Zvárová, the dialogues that brought us together and the content of our last conversation. It explores some imagined topics that we might still have been discussing together today and contemporary digital health-related matters that might have been of interest to Jana.

Keywords

Bio-informatics; Current directions; Developments; Digital health; Policy

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1 Introduction

Careers can be like woven fabrics. My own career has been like a journey through an organic landscape [1].[1] I have moved in sequence through several disciplinary areas. Originally grounded in the social sciences, my work has involved that discipline's methodological contributions to a number of fields – including health and the implementation of health-related services. For four decades now, my focus has been on the protection of people's rights in a good information and communication technology (ICT) society [2, 3]. Increasingly, my concentration has been on societies that are sound and full of well-being [4], and in which people continue to age actively and healthily.

Careers can also be much more sequential. Professor Jana Zvárová's academic career was clearly firmly in biomedical informatics. Yet her intellectual and personal concerns were much broader. She seemed particularly interested in placing biomedicine in its wider societal context. She set her own professional and career developments in a context that would offer a positive work-life balance. She always wanted to provide intellectual stimulus to young people, and she was especially encouraging of women younger than herself as well as of her own age.

Our careers were in many ways very different. Yet, our professional conversations were immediately interesting, engaging, and – above all – warm, ever since some first discussions when Jana had visited the European Commission in Brussels as an external expert evaluating health informatics' proposals and reviewing project outcomes.

As summer approaches in the beautiful city of Prague, it is with considerable pleasure that I recall my last personal meeting five years ago with Jana.

2 Last Conversations

Conversations can take place in many settings in many locations. Physically, in the context of the June 2013 ICT, Society and Human Beings conference, Jana and I met and shared supper in an outdoor garden café near the city centre, close to the university buildings in the Czech capital.

My last evening meeting with Professor Zvárová took place shortly prior to Jana's founding of the EUROMISE Mentor Association. She was full of her plans for the future, the association and publications.

We discussed at length some of the upcoming societal and social trends in digital health. Jana expressed considerable interest in my presentation at the 2013 ICT, Society and Human Beings conference that encapsulated some first thoughts around the parallels between Slow Food and Slow Tech [5]: the emphasis was on good, clean, and fair technologies. These ideas, especially those on environmentalism and sustainability, were inspired in part by the writings of challenges to the future of humankind by former American Vice-President, Al Gore [6]. I was at

[1] Section 3 of this article is in particular an adaptation and re-working of part of this earlier publication.

an early stage of making preparations with my Italian co-author, Norberto Patrignani, to write a book on responsible, sustainable, and ethical technology [4], and initiatives to support Swedish colleague, Gunilla Bradley, on her own volume on the Good Information and Communication Society [3].

Of course, we continued to have many electronic mail exchanges following that. In the winter, spring, and summer before her death, Jana, Pirkko Nykänen and I had many email interactions, planning the publication of our co-edited special issue on women in health informatics [7].

3 Digital Health Directions

People always matter; they should be at the forefront. Chiefly, the 'person' or 'patient' is now being placed 'at the centre' of the (health or care) system or service. Of course, there can be many interpretations of this centeredness including, on the one hand, versions that are benign in their orientation and, on the other hand, ones that imply greater demands on the individual's own time, resources, and efforts – with fewer services provided by others.

Data as an issue is becoming more important. This change in orientation probably implies that much more support work will be needed by all individuals, with regard to the meaning, and maintenance, of their own data and their own systems. It will be particularly fascinating, and challenging, to see and understand how the General Data Protection Regulation [8] will be applied in the European Member States from May 2018 onwards, and what will be its particular implications for the health and care sectors. Those who work especially with older adults are concerned with regard to the competences needed by mature generations of citizens – who may or may not have the forms of 'literacy' needed to cope with changes in data-handling and data-sharing in a range of fields that are converging.

Similar questions can also be asked about employees in the health and care fields. Exciting research continues in the fields of organisational theory and behaviour. Labour is becoming more and more commoditised, as much in health and care services as in other professions and occupations.

Over the past decade of policy directions – and especially in later years, it has been the financial aspects of health systems and services that have been predominant, with a focus on what new business models of health need to be developed.

Technologies are coming ever closer to people physically, including the fact that they are being inserted inside human bodies. There is increasing convergence in the computational world, articulated in discussions on the brain, body, and being going back to 2010[2], and before.

It remains critically important to explore the societal and ethical implications [9] and human needs in relation to technologies in general and digital health specifically [10, 11]. As I first worded it a decade ago [12]:

As we look towards the future, and particularly that peak in the West of baby-boom ageing around 2030, all citizens in our societies need to ask themselves certain basic questions. How [to find a balance] *between those who need care and support and those few(er) who are economically active; between those regions and states which are blessed with abundant healthcare professionals and those which have insufficient; between those countries and institutions which extract the benefits of advanced telemedication and teleconsultation and those which remain as yet unconnected? How too can we move towards a more innovative and evolutionary view of thinking about and organising our healthcare systems and services?*

4 Contemporary Developments and Reflections on Professor Zvárová's Fields of Interest

Biomedicine remains a core topic of interest. As Reinhold Haux and colleagues concluded last year: "There is a high chance that [bio-medical and health informatics (BMHI)] will continue to flourish as an important discipline; its innovative interventions might then reach the original objectives of advancing science and improving health care outcomes" [10, 13].

Certain criticisms can be made, however, of the biomedical field [13]. Highlighting that advances in personalised medicine cannot be achieved in isolated situations or narrow settings, the panellists cited in this 2017 article pointed to the need for increased stakeholder engagement and involvement: today, one of these areas of increased involvement is predicted to be on the part of patients. Some panellists, who participated in the three (2015-2016) conferences at which experts for the Haux et al. article were interviewed, were especially critical of a contemporary trend (which suggests that health care and medical professionals accept vendor-supplied solutions and technologies in their routine work, without any particular questioning of them). In parallel, the interviewees observed that many informatics tools are developed and used without input from informatics professionals.

Professor Zvárová would surely currently be showing keen interest in the actions of Member States, and their research institutions to implement plans to link genomic data and biobanks to electronic health record systems that are being made accessible to citizens through patient / user portals.

Jana would today, no doubt, be intrigued by current developments in European and international policy in the field of digital health.

With her background in biomedicine and medical statistics, one can imagine that Jana might also

[2]https://www.itas.kit.edu/downloads/ta-kalender_20100518_cfp_converging_technologies_ifip_wg9.pdf

contemporarily be particularly interested in the second of the three bullets covering areas flagged up during the Digital Single Market mid-term review [14]. Its focus is on support for data infrastructure, with a view to ensuring progress being made in the field of research:

- Citizens' secure access to electronic health records and the possibility to share these across borders.
- Support data infrastructure to advance research, prevent disease and personalise health and care in key areas.
- Facilitate feedback and interaction between patients and healthcare providers enhance disease prevention and empower people to take responsibility for the management of their own health.

These are priorities that will be emphasised in a forthcoming Commission Communication on enabling the digital transformation of health and care in the Digital Single Market, due to be published around May 2018. It is anticipated that the Communication will identify actions by the European Commission, Member States and stakeholders: these will be intended to empower citizens and contribute to a healthier society. Here too, industry players – as in many other spheres – seem to be set to take on a higher involvement profile.

Jana would surely also be paying close attention to her own country's Health Ministry's endeavours to set up a National eHealth Centre during 2018-2019, undertaken with technical expertise and in close cooperation with similar ministries from both Austria and Denmark.[3]

Jana's focus on the future career directions of young people, especially researchers, would certainly find reflection in the educational and training directions taken by contemporary Horizon 2020 research Calls [15]. Areas include rare diseases, neuro-generative diseases, regulatory science, chronic conditions, digital health literacy, digital health and care, and cyber-security.

5 Conclusions

For all of these current, many and various reasons, it is good news to know that Professor Jana Zvárová's interests and concerns are being represented in today's 4 May 2018 Jana Zvárová Memorial Conference. It brings together in a vibrant, on-going community both her old and new colleagues, friends, and family.

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Remembering Jana Zvárová (1943-2017)

Jan H. van Bemmel, Marion Ball, Arie Hasman

We were all shocked when hearing that Dr. Jana Zvárová had passed away on July 5th, 2017. She was one of the most active members within IMIA and EFMI and perhaps the very first person in our field from the former East-European countries.

Jana Zvárová was born in 1943 in Prague, Czechoslovakia. After graduating in Mathematics in 1965 at the Faculty of Mathematics and Physics of Charles University in Prague, she collaborated with several disciplines of Charles University (Medicine, and Mathematics and Physics). She founded the Medical Informatics section of the Czech Society of Biomedical Engineering and Medical Informatics in 1978. She was nominated in 1999 full professor at Charles University and received in the same year the highest Czech scientific degree of Doctor of Sciences at the Academy of Sciences of the Czech Republic.

Dr Zvárová systematically applied new theoretical knowledge in biomedicine, particularly in epidemiology and public health. Since 1994, she chaired the *European Center of Medical Informatics, Statistics, and Epidemiology (*EuroMISE) of Charles University and the Academy of Sciences. Between 2006 and 2011, she was the director of the *Center of Biomedical Informatics*. She was the representative of the Czech Republic in IMIA (the International Medical Informatics Association) and in EFMI (the European Federation for Medical Informatics). She was a member of editorial boards of several national and international journals. The results of her research are documented in 10 monographs and more than 300 articles in peer-reviewed journals.

In the framework of European projects, she started new lines of research and education concerning electronic health records, knowledge representation in clinical guidelines, decision support systems, and methods for evaluation of

knowledge. She organized several IMIA and EFMI international conferences and workshops in Prague. Dr Zvárová also initiated the foundation of the EuroMISE Mentor Association focusing on international cooperation in student mentoring activities.

Perhaps, Jana Zvárová's first visit to an international conference was in 1983, when she attended Medinfo 83 in Amsterdam, IMIA's tri-annual World Conference on Medical Informatics. Since that time, Jana organized many meetings and projects herself, in close collaboration with several colleagues from abroad. During the past years, we have learned to know many active members in IMIA and EFMI; all of them were active and energetic, but hardly any of them could be compared with Jana Zvárová, whose creativity and endeavors were far beyond those of all others.

Already in September 1985, Jana took the initiative to organize in Prague a Conference on Medical Decision Making, covering diagnostic strategies and expert systems. Jana requested François Grémy and Jan van Bemmel to chair this four-day meeting in which also people from then communist countries took part. An important book from North-Holland Publishing Company was the result of this conference, the first one of that kind in the communist world.

The years before 1989 were very difficult, but already before that year Jana managed to start research projects, organize international and local meetings, and to travel abroad. But after the so-called velvet revolution, things improved radically. For instance, Jana's Center took the initiative to organize courses in Medical Informatics at a new center of the Academy of Sciences in Prague, where she had established her own research activities. The Academy of Sciences, Charles University, and the European Union gave support to this initiative and the result was that during four years, 1996 – 1999, three-week courses in Medical Informatics were given each year for about 20-25 students, with hands-on experience. We want to stress that it was Jana who organized such projects and that they were accomplished only thanks to her perseverance.

Not only was Jana a professional of the first order, she also was a devoted wife and mother having raised very successful children and being a role model for women in the field of Health Informatics internationally. Shortly before her death she planned to publish a special issue on *Women in Health Informatics* in the *International Journal on Biomedicine and Healthcare*, to appear in the autumn of 2017, to which many of the international medical informatics female professionals were invited by her to make a contribution.

Jana's energy was amazing, even until only a few months before she passed away, when she organized once more a conference here in Prague at the House of Physicians. Of course, after so many years, several other stories could be told, but we will finish by repeating once more that everyone was deeply impressed by Jana's personality. Jana knew exactly what she wanted, but was at the same time a warm and friendly person. Together with all other colleagues in EFMI and IMIA, we were always much delighted to give support to Jana's initiatives. Personally and professionally we do miss Jana dearly. It has been indeed an honor to have been counted to her friends.

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