INTERNATIONAL JOURNAL OF MEDICAL INFORMATICS 79 (2010) 599–610

journal homepage: www.intl.elsevierhealth.com/journals/ijmi

Commentary

Medical informatics: Past, present, future☆,☆☆

*Reinhold Haux**,[1]

Peter L. Institute for Medical Informatics, University of Braunschweig – Institute of Technology and Hannover Medical School, Muehlenpfordtstr. 23, D-38106 Braunschweig, Germany

ARTICLE INFO

Article history:
Received 24 May 2010
Received in revised form 6 June 2010
Accepted 6 June 2010

Keywords:
Medical informatics
Health informatics
Biomedical informatics
International Medical Informatics Association
IMIA

ABSTRACT

Objective: To reflect about medical informatics as a discipline. To suggest significant future research directions with the purpose of stimulating further discussion.
Methods: Exploring and discussing important developments in medical informatics from the past and in the present by way of examples. Reflecting on the role of IMIA, the International Medical Informatics Association, in influencing the discipline.
Results: Medical informatics as a discipline is still young. Today, as a cross-sectional discipline, it forms one of the bases for medicine and health care. As a consequence considerable responsibility rests on medical informatics for improving the health of people, through its contributions to high-quality, efficient health care and to innovative research in biomedicine and related health and computer sciences. Current major research fields can be grouped according to the organization, application, and evaluation of health information systems, to medical knowledge representation, and to the underlying signal and data analyses and interpretations. Yet, given the fluid nature of many of the driving forces behind progress in information processing methods and their technologies, progress in medicine and health care, and the rapidly changing needs, requirements and expectations of human societies, we can expect many changes in future medical informatics research. Future research fields might range from seamless interactivity with automated data capture and storage, via informatics diagnostics and therapeutics, to living labs with data analysis methodology, involving sensor-enhanced ambient environments. The role of IMIA, the International Medical Informatics Association, for building a cooperative, strongly connected, and research-driven medical informatics community worldwide can hardly be underestimated.
Conclusions: Health care continuously changes as the underlying science and practice of health are in continuous transformation. Medical informatics as a discipline is strongly affected by these changes and is in a position to be a key, active contributor in these changes.

☆ Dedicated to IMIA, the International Medical Informatics Association. Besides the honour to serve in IMIA during the last 15 years as Working Group Chair, as Board Member, as co-editor of the IMIA Yearbook and, now, as its President, I am grateful for the opportunity of meeting so many exceptional people at events of IMIA and of IMIA's member societies. The author has benefited much from their knowledge and insights during the course of countless discussions.

☆☆ Written, extended version of a sequence of lectures, given on November 11, 2009, at CoMHI2009 in Hiroshima, Japan, on September 6, 2010, at gmds2010 in Mannheim, Germany, and on September 13, 2010, at Medinfo2010 in Cape Town, South Africa.

* Tel.: +49 531 391 9500.
E-mail address: Reinhold.Haux@plri.de.
URL: http://www.plri.de.

[1] President of IMIA (2007–2010).

1386-5056/$ – see front matter © 2010 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.ijmedinf.2010.06.003

1. Introduction

1.1. Aim and structure

The aim of this essay is to reflect about medical informatics as a discipline.

Its main goal is to emphasize some promising future research directions which may become important parts of medical informatics (Section 4) while at the same time stimulating further discussion within our scientific community on these topics. In order to do this, it is helpful to be aware of important current aspects of the discipline (Section 3), and learn from past experience (Section 2). In all of these sections, emphasis will be placed on the role of IMIA, the International Medical Informatics Association [1], in influencing the direction of our discipline.

1.2. Related work

This is most certainly not the first, and is unlikely to be the last of this kind of reflection. Other debates about our discipline as a whole (or at least its major parts) can be found in [2–7] (in chronological order). These papers focus on questions on research aims and their corresponding challenges. Other papers focus more on research aims in the context of describing the discipline of medical informatics ([8–18], in chronological order).

Last, but not least, there exist some historical 'milestones', where sets of papers have been gathered into special issues of journals in order to critically discuss the aims, scope and challenges of our discipline. Three of them, again with a focus on questions of research aims, will be mentioned here. In 1983 a SCAMCI-sponsored workshop on 'medical information sciences' took place in Washington (DC), USA, discussing among other questions about "principal research issues" [19, p. 167]. Although its scope was broader, this issue contained a couple of papers dealing with research (e.g. [20–22]). In 2001 in Madrid, Spain, a conference on challenges for medical informatics as an academic discipline took place. Major results have been published in [23] (see e.g. [24–29]). In 2008 on the occasion of the 35th anniversary of the Heidelberg/Heilbronn curriculum of medical informatics a symposium on perspectives of medical informatics took place in Heidelberg, Germany. Results have been published in [30] (see e.g. [31–38]).

In this context it should be added that from time to time documents from committees, established by government or government-related institutions and professional societies, also discuss such challenges, mainly in order to define funding strategies or professional directions. Examples are published in [39,40].

I still appreciate the generous offer of the now Editor Emeritus of the International Journal of Medical Informatics (IJMI), Arie Hasman, for not only giving me the opportunity of publishing a paper in 1997 on the aims and tasks of medical informatics [4], but also for his editing of a complete issue in IJMI debating and significantly adding to my suggestions on aims and tasks of medical informatics (e.g. [41]).

1.3. A modest definition of medical informatics

Many definitions of medical informatics as discipline can be found in the literature aiming at broad coverage and completeness. Here I simply want to refer to medical informatics as the discipline, dedicated to the systematic processing of data, information and knowledge in medicine and health care [42].

1.4. Limitations

First, reflections such as those in the present paper, are necessarily subjective and biased by the author's background, i.e. his education, his professional career, his cultural and society roots.

Second, this essay does *not* intend to discuss the name of our discipline and its various subfields, although our discipline has had more than its share of such discussions, and even though such debates have been contributing to our discipline's development and its role in the practice of health care, education and research. Let me just mention that the meaning of the terms health informatics and medical informatics, and now also biomedical informatics, varies within and between different groups and geographical regions. The term medical informatics is used here in the broad and comprehensive meaning as defined in Section 1.3. For a more detailed discussion see e.g. [43]. Others may have preferred to use one of the other two names, mentioned above.

2. Medical informatics—some milestones of the past

2.1. On the history of medical informatics

Medical informatics as a discipline is still young, in particular when you compare it with other medical disciplines. Yet, we can look back to a past of about 50 years, not to mention earlier roots on approaches for systematically processing of data, information and knowledge in medicine and health care in earlier history.

Our discipline's development correlates clearly with the invention and, within few decades, rapid dissemination of digital ('von Neumann') computers and the development of information and communication tools based on these computers. As important as this development in information and communication *technology* (ICT), these tools enabled a significant development in information processing *methodology*, which made up the other part of these amazing developments.

Within the past decades societies in general, and medicine and health care in particular, have tremendously changed, also by the developments mentioned before. Through this change health care has been significantly impacted and improved. We can hardly imagine diagnostic procedures without, for instance, diagnostic imaging tools such as computer tomography, or therapeutic actions without the software that checks for medication interactions or uses computer-assisted tools for surgery, or for accessing medical knowledge without, for instance, accessing knowledge bases on high-quality publications, and without accessing and recording patient data in electronic records as part of computer-supported hospital

information systems. Just imagine medicine and health care without information and communication *technology*. And be aware of the information processing *methodology*, which would be deeply missed.

In 2007 IMIA celebrated its 40 years of existence [44–48]. The association's publication list on medical informatics research, education, and practise [48], prepared for this occasion, provided an impressive example of how medical informatics has developed so rapidly and effectively as a discipline.

The early roots of our discipline, including its name, have been described by Collen in [49]. The report of the Reisensburg Conference in 1972, significantly affecting the medical informatics development in Germany (and beyond), has for a long time been only accessible for a limited German-speaking readership. Thanks to Moehr we are now all having the opportunity to access this document [50,51]. A look at the history sections of the IMIA Yearbooks of Medical Informatics [52] also illustrates how rapidly the field has developed. The history section was introduced in 2006 with reports of Collen [53] and Peterson [54].

Although there have been several attempts to document the history of our field, a comprehensive history of medical informatics, considering the developments in all regions of our world, is still missing. I am glad that the IMIA Board decided at its 2009 meeting in Hiroshima that a task force, chaired by Casimir Kulikowski, has been established in order to prepare a framework for documenting the worldwide developments in our field, so that during the next few years it will become available—at the latest at IMIA's 50th birthday.

2.2. *Looking back 50 years*

Let us now briefly look back 50, 25, and 10 years, to highlight at least some of the milestones for this rapid and impressive development.

In 1959, 50 years ago, Ledley and Lusted's landmark paper on diagnostic decision-making appeared in Science [55], reviewing methods for handling decision-making under risk and uncertainty, and providing the first comprehensive discussion needed for subsequent work on computer-based medical decision-support.

2.3. *Looking back 25 years*

In the period 1984/1985, 25 years ago, several papers, which strongly influenced the development of medical informatics, were published, four of which I will comment on next.

- van Bemmel presented a structural framework of medical informatics, which provided a basis for understanding the scope of methodological and technological knowledge, needed in this discipline [20].
- Reichertz discussed functional and architectural perspectives of hospital information systems [56]. Being both chief information officer and director of research and education at the Medical School in Hannover provided him with unique insights into this kind of research.
- Shortliffe highlighted the experimental characteristics of our discipline with the implications for the research methodology needed to achieve good scientific practice [22]. His paper was originally published in the proceedings of another important workshop at this time, taking place in Chamonix, France, on informatics and medical education [57].
- Willems et al. reported about a then recently initiated international project, aimed at standardizing computer-derived electrocardiogram analyses [58]. This project significantly contributed to evaluating computer-based application systems for knowledge-based decision-support in general and, in particular, their underlying concepts and methods. Six years later the published study showed that some computer programs for the interpretation of electrocardiograms performed almost as well as cardiologists in identifying major cardiac disorders [59] and so highlighted the relevance of medical informatics for medicine and health care.

2.4. *Looking back 10 years*

In the years 1999/2000, 10 years ago, IMIA endorsed [60] and published [61] the first international recommendations on education in medical informatics. These recommendations have been widely used and referenced, as well as being translated into many languages [62]. This document is a clear sign of the international presence and maturity of medical informatics as a discipline. Education in medical informatics grew and flourished during these five decades and now takes place in almost all countries, though at quite different levels.

In 1999 Gardner et al. reported on two decades of work on the HELP system [63], and so on successfully implementing knowledge-based decision-support as part of the information system of the LDS hospital at Salt Lake City.

Both publications point out the growing maturity of medical informatics. The IMIA recommendations on education also show that a certain international consensus had been achieved on the scope of medical informatics as a discipline.

3. Medical informatics—its role today and snapshots of the present

3.1. *The role of medical informatics today*

In its early days medical informatics might have been considered as a 'nice-to-have' (but not 'need-to-have') discipline, both in biomedicine and health sciences as well as in computer science. In German this might be termed an 'orchid discipline' as being just a nice orchid in the garden of the sciences.

When looking back at the development of medical informatics, we can recognize that it has been growing steadily (see e.g. [64] in terms of published research), and that today, as a cross-sectional or bridging discipline, medical informatics forms one of the bases for medicine and health care. As a result much is expected of medical informatics to help achieving health for people throughout the world, both in contributing to the quality and efficiency of health care and to innovative biomedical as well as computer, health, and information sciences research.

Medical informatics has changed today, insofar as, in addition to research and later education, many informaticians

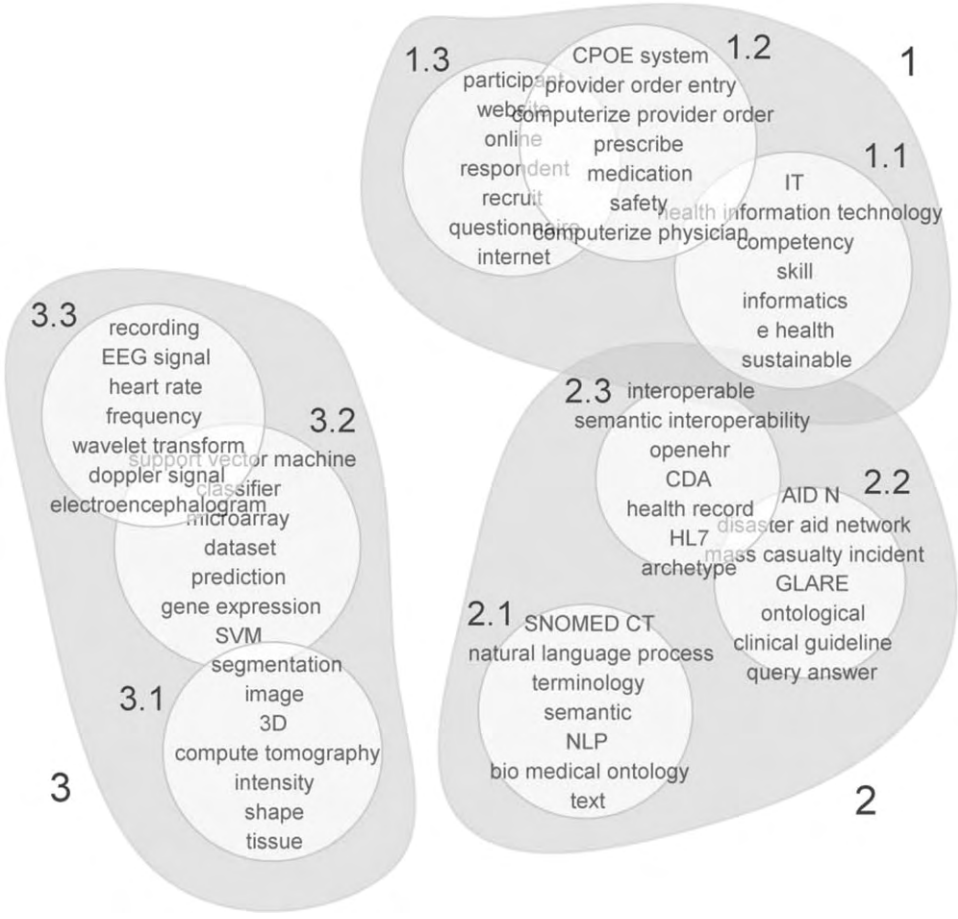

Fig. 1 – Extracted clusters of 3660 articles belonging to 16 medical informatics journals, appearing between 2005 and 2008. Details in [81], where this figure is taken from, p. 80.

are working in the practice of health care, e.g. in health care institutions and in 'health care ICT industries'. Informatics methodology and ICT not only have become a major factor for quality and efficiency of health care worldwide, but it has also emerged as a major contributor to the worldwide ICT market. While precise figures are difficult to estimate, some, indicating its significance (taken from [65], Section 2.3.2), show that for the USA the estimated total expenditures of ICT equipment and software in health care was about 21 billion US$ in 2007, or 8.1% of USA's total ICT expenditures [66]. Reports from the European Union (EU) state that the 'eHealth industry' in the EU (defined as comprising clinical information systems, telemedicine and homecare, and regional networks) was estimated "to be worth close to 21 billion € in 2006" and that the global eHealth industry "has the potential to be the third largest industry in the health sector with a global turnover of 50–60 billion €" [67]. Many countries have established programs to stimulate information and communication technology applications in the eHealth segment, with investment estimated at between 50 million US$ and 11.5 billion US$ [68].

What is IMIA's role in this context? As indicated in IMIA's statutes and on IMIA's web site [1], the association's goals and objectives include:

- to promote informatics in health care, public health and biomedical research;
- to advance international cooperation;
- to stimulate research, development and routine application;
- to move informatics from theory into practice in the full range of health and care settings;
- to further the dissemination and exchange of knowledge, information and technology;
- to promote education and responsible behaviour;
- to seek and maintain formal channels of communication with any relevant professional or governmental organization.

Covering all continents of the globe, more than 50 member societies and more than 50 academic institutions belong to IMIA. IMIA's member societies represent over 50,000 individuals, while IMIA is recognized as one of the World Health Organization's (WHO) non-governmental organizations [69].

IMIA's role is well defined by its objectives. IMIA supports and stimulates high-quality translational communication, research, education, and practice in medical informatics. This is done by bringing together scientists, researchers and informatics practitioners from across the world in an environment of cooperation and sharing at IMIA's conferences, with its Med-

Table 1 – Assigned model types in all publications of the International Journal of Medical Informatics (IJMI) and Methods of Information in Medicine (MIM) in the years 2004 and 2005. Details in [83], where this table is taken from, p. 639.

Model types for modelling by A.H./R.H.	Biological processes	Communication processes	Decision processes	Engineering processes	Educational processes	Organizational processes	Computational processes
In IJMI (n.pub. = 190)	4/4	55/98	30/24	76/34	32/32	40/141	11/10
In MIM (n.pub. = 194)	41/82	17/57	22/106	38/38	6/2	14/69	86/79
$\sum$ (n.pub. = 384)	45/86	72/155	52/130	114/72	38/34	54/210	97/89

info world congresses being the most prominent of them. Publishing activities, with the IMIA Yearbook of Medical Informatics as its 'flagship', and its endorsed and white paper documents and recommendations form the other important aspects of IMIA's role today. Recent significant examples include the recently revised IMIA recommendations on education, led by Mantas et al. [70], the IMIA endorsed "statement on reporting of evaluation studies in health informatics", led by Talmon [71], and IMIA's strategic plan 'towards IMIA 2015', led by Lorenzi and Murray [72–74], which also reflects on appropriately positioning medical informatics as a discipline. Further recent details and comments on IMIA can be found in reports, published during my term as IMIA President [75–80].

3.2. *Snapshot 1: searching for research fields by clustering n-grams of medical informatics literature*

To identify major current medical informatics research directions, I now offer three illustrative 'snapshot' examples.

In 2009 Schuemie et al. [81] published results of an investigation, aiming at characterizing medical informatics by studying its scientific literature. The authors analysed MEDLINE referenced medical informatics articles published between July 1993 and July 2008. Research fields were identified by extracting n-grams, or sequences of n words, occurring either in titles or abstracts as stored in MEDLINE ($n \in \{1,2,3\}$). Based on these n-grams, the authors then clustered articles by using a minimum entropy algorithm. Details are described in [81].

In Fig. 1 the extracted clusters of 3660 articles from 16 medical informatics journals are presented, appearing during the last three years of their study, i.e. between 2005 and 2008. Schumie et al. suggest that, according to their analyses, current medical informatics research concentrates on three research fields. These fields are

(1) the organization, application, and evaluation of health information systems,
(2) medical knowledge representation, and
(3) signal and data analysis.

Although the authors say that medical informatics as a discipline has remained relatively stable over the last 15 years (the range of their analyses), they see certain shifts during the last three years towards clinical provider order entry (CPOE) and user evaluations, natural language processing, formalization of guidelines, and the development of standards for patient records.

3.3. *Snapshot 2: identifying model types by indexing medical informatics literature*

Modelling is a central part of medical informatics research, education and practice (e.g. [82]). In [42] seven non-disjoint 'core model types' for modelling biological, communication, decision, engineering, educational, organizational, and computational processes were distinguished.

In 2006 [83] and 2007 [84] Hasman and myself reported about a retrospective, prolective observational study on publications of the two official journals IMIA, the International

Year (# of papers)	1. Health & Clinical Management	2. Patient Records	3. Health Information Systems	4. Sensor, Signal & Imaging Informatics	5. Decision Support, Knowledge Representation & Management	6. Educational & Consumer Informatics	7. Bio-informatics
1980 (279)	18	8	14	28	28	4	NA
1983 (318)	12	7	29	21	23	8	NA
1986 (275)	8	7	30	15	28	12	NA
1992 (256)	14	11	19	16	30	10	NA
1998 (263)	7	23	18	10	23	15	4
2001 (281)	21	16	6	4	39	11	3
2004 (302)	25	15	8	2	35	10	5

Fig. 2 – MEDINFO full papers presented by subject areas (% total/year) between 1980 and 2004. All numbers in the table are percentages of the totals for the year. Details in [46], where this figure is taken from, p. 180.

Journal of Medical Informatics and Methods of Information in Medicine. All 384 publications of the years 2004 and 2005 from these journals have been analysed by us and were indexed according to these seven model types. The results are shown in Table 1. Details are described in [83,84].

Despite an unexpected high interobserver variability we can see that the majority of papers could be assigned to types of modelling either decision, engineering or communication processes.

The identified major modelling types do not appear to strongly correlate with the three research fields, identified in the analysis of Schumie et al., although communication as well as decision processes may primarily be in research on the organization, application, and evaluation of health information systems.

3.4. *Snapshot 3: determining major subject areas of medical informatics by categorizing Medinfo full papers*

In his paper on coalescing medical informatics worldwide, Kulikowski describes the development of medical informatics as discipline from the viewpoint of the start and the development of IMIA. Mayor research fields of medical informatics were among others analysed by counting the number of full papers at IMIA's Medinfo world congresses. The seven subject areas have been taken from the IMIA Yearbook of Medical Informatics 2006. Details are described in [46].

The results of the mentioned analysis are shown in Fig. 2. We can see from this investigation that from this point of view current major fields of medical informatics are decision-support, health and clinical management, and patient records. Again, research on the organization, application, and evaluation of health information systems (here mainly in subject areas 1, 2, and 3) dominate, together with research on medical knowledge representation (here mainly in subject area 5). To some extent similar to [81], it could be seen that, with few exceptions, the relative importance of these medical informatics research fields (here rated by the frequency of publications) has remained quite stable.

All fields of research can be assigned to the three application areas:

- medical informatics contributing to good medicine and good health for the individual,
- medical informatics contributing to good medical and health knowledge, and
- medical informatics contributing to well-organized health care.

4. Medical informatics—thoughts about the future

4.1. *Recapitulating the aims of medical informatics*

Systematic processing of data, information and knowledge in medicine and health care does not exist for its own sake. Medical informatics is neither sufficiently defined by its *methodology and technology* on the one hand, nor by its *application domain* (such as the three application areas mentioned before) on the other hand. As usual for most disciplines, it also has practical *aims*, which for medical informatics are twofold:

- to contribute to progress in the sciences and
- to contribute to high-quality, efficient health care.

Today and probably in the future, health care and human life style choices will become increasingly overlapping, as the critical interrelationships and confluences become better understood. Insofar as the aim of high-quality, efficient health care improves the quality of life, medical informatics will also contribute to improving the range of beneficial personal choices and self-sufficiency (autonomy) for those living increasingly longer in our aging societies.

4.2. *Driving forces of medical informatics*

Before discussing important future research aims let us also envision and recall the driving forces of medical informatics, influencing these research directions. As mentioned in Section 3, we can see a couple of such driving forces influencing medical informatics research. Three (by no means disjoint, independent) major driving forces are

- progress in information processing methodology and information and communication technology,
- progress in medicine and health care, and
- changes in needs, requirements and expectations of societies.

Usually, as medical informaticians, we are quite well aware of the latest developments in informatics and medicine. We are very conscious that today we live in a highly interconnected world with ubiquitous computing facilities and sensor-enhanced ambient environments. In addition, as mentioned, health care and life styles overlap more and more, with considerable consequences for information processing tools and the services that are expected of them.

In the future, sharing of knowledge for research and education will take place increasingly on a global level. Medical informatics is included in this trend, which also effects the offerings of products and services for health and health care (e.g. [85]) and is also affecting the organization of health care and the health ICT industry. As noted by Teilhard de Chardin in the 1950s, we are developing towards a 'noosphere' of global knowledge, interconnectedness and conscience [86]. We can observe that in addition to regional and national 'ICT strategies' there are now also substantial activities on the global level. Considering the 'information society' as a new challenge and opportunity, the United Nations (UN) implemented in 2003 the 'World Summit on the Information Society' [87]. A recent status report informed globally about national 'e-strategies', including 'eHealth' as a branch [88]. WHO approved at its 58th World Health Assembly in May 2005 an eHealth resolution with a global commitment, urging WHO's member states "to consider drawing up a long-term strategic plan for developing and implementing eHealth services in the various areas of the health sector" [89]. As a consequence, WHO established an eHealth observatory, providing among other items, global progress reports on informatics dissemination and its impact on quality and efficiency of care [90–92].

Regarding changes in the needs, requirements and expectations of societies as driving force, significant change arises due to higher life expectancies. Quoting from a recent UN report [93]:

- "Population ageing is unprecedented, a process without parallel in the history of humanity. ... At the world level, the number of older persons [persons aged 60 years or over] is expected to exceed the number of children [persons under age 15] for the first time in 2045. ... Population ageing ... is affecting nearly all the countries of the world." [93, p. viii];
- "In 2000, the population aged 60 years or over numbered 600 million, triple the number present in 1950. In 2009, the number of older persons had surpassed 700 million. By 2050, 2 billion older persons are projected to be alive, implying that their number will once again triple over a span of 50 years. ... The population of older persons is itself ageing. Among those aged 60 years or over, the fastest growing population is that of the oldest-old, that is, those aged 80 years or over." [93, p. ix];
- "Between 1950 and 2009, the potential support ratio [the number of persons aged 15 to 64 for each older person aged 65 years or over] declined from 12 to 9 potential workers per person aged 65 or over. By 2050, the potential support ratio is projected to drop further to reach 4 potential workers per older person" [93, p. x].

In particular, the tremendous reduction of the potential support ratio, an indicator of how many potential workers there are per older person, has dramatic economic and health implications for societies. It also suggests that there is greater urgency for changing lifestyles, including health care, which can be considerably aided or enhanced by informatics tools and services.

4.3. *Two views on important future research fields*

As mentioned in the beginning, the main goal of this essay is to discuss important future research fields in medical informatics. Important means here that – based on the aim of medical informatics – these research fields are of significant *originality*, i.e. that they significantly introduce and explore new theories, concepts or methods *and* that these fields are of significant *relevance*, i.e. that they significantly contribute to efficient, high-quality health care and to improvements in quality of life and/or to the progress of biomedicine and the computer, health and information sciences.

Let me now take two different points of view in order to present important future research fields. The first one might be regarded as the more traditional one, being an 'evolutionary' approach, based on earlier proposals. The second one might be seen as the more radical one, starting from a future vision and hence being more 'revolutionary'.

Here is the first view. In building on the suggestions for important future research fields in the years between roughly 1990 and the mid-2000s (mainly referring to [2–4], partially updated in [94,95], to [5,7,9,23], there in particular [26]) and in grouping these fields into the application areas, mentioned in Section 3.4, 10 important future research fields might grouped and denoted as

medical informatics contributing to good medicine and good health for the individual

1 comprehensive electronic patient records (or electronic health records), combined with appropriate concepts for representing, accessing and visualizing health data;

2 computer-enhanced decision-support for health care professionals, combined with appropriate concepts for reasoning and knowledge representation;
3 comprehensive measurement and visualization of the human body;
4 formal models for better understanding the functions or workings of the human body;

medical informatics contributing to good medical and health knowledge

5 comprehensive, easily accessible medical/health care knowledge bases;
6 data mining and analysis for health reporting, health consulting and for identifying new medical knowledge;
7 controlled medical vocabularies and their relation to models of health and disease;

medical informatics contributing to well-organized health care

8 effective architectures of health information systems for patient-centered (not institution-centered) care and appropriate information management methods;

with all these research fields being related to

9 understanding nature, properties and management of information in biological structures as well as in health care organizations;
10 demonstration of effectiveness through evaluation studies.

Let me also suggest to take a different view from a, maybe, more general perspective. Having in mind that today and in the near future

(a) health has to be considered more and more as an integral and continuous part of life (not as health care within in a limited time frame of a disease episode),
(b) medical informatics is addressing both, health professionals (plus their professional environment) *and* individuals/consumers (plus their social environment),
(c) the individual, the human being, is being at the center of research, even though medical informatics research can range in scale from molecules to populations,
(d) research, education and practice may shift more and more from local to global activities,
(e) these important future research fields, grouped as before, might in this second view also be structured into 16 groups and denoted as

medical informatics contributions to good medicine and good health for the individual

1 seamless interactivity with automated data capture and storage for patient care, and beyond (from perception to high-level semantic concepts, related to human–human, machine–machine, as well as human–machine interaction; 'beyond' in the meaning of not being restricted to certain disease episodes);
2 knowledge-based decision-support for diagnosis and therapy, and beyond (with decision-support in its broadest meaning, i.e. from simply pointing persons to important knowledge by identifying latest results in knowledge bases to context-aware, individualized decision proposals using formally represented knowledge; 'beyond' in the meaning of also including, e.g. prevention);
3 patient-centered data analysis and mining (with representations of patient data based on appropriate semantic concepts);
4 informatics diagnostics, where informatics tools (with corresponding methodology) form the major part of the diagnostic entity;
5 informatics therapeutics, where informatics tools (with corresponding methodology) form the major part of the therapeutic entity;
6 informatics capability-enhancing extensions, both mental and physical, to overcome (e.g. age-related) functional deficits (both external or internal to the human body, serving as implanted, immersive or external assistants, and providing a person with extended memories, senses, and connectivity);

medical informatics contributions to good medical and health knowledge

7 systematization of medical/health knowledge (with formal representation, automated knowledge collection, beyond languages);
8 analysis of medical and health knowledge (including knowledge generation, semantic integrity, assessing and certifying quality of knowledge);
9 identifying new disease patterns (e.g. using ubiquitously available patient information and medical/health knowledge, through, e.g., pervasively measured sensor data from individuals, and, e.g., by combining such data with molecular and clinical knowledge within social and living contexts);
10 modelling the virtual human (for enabling more 'in vitro experiments' through simulation and so reducing 'in vivo experiments' through trials and observational studies);

medical informatics contributions to well-organized health care

11 elaborating concepts for appropriate health data bank architectures and for its organizations (allowing a range of local to global offerings for storing and maintaining personal health data);
12 elaborating concepts for patient-centered health information system architectures (within and in particular beyond health care institutions, allowing multiple usability of data) and its information management strategies (e.g. also considering data from ambient environments such as 'intelligent' buildings, and external, implanted or immersive body sensors);
13 automated, individualized health advice and education;

with all these research fields being related to

14 analysing, creating and/or extending theories, concepts, and methods;
15 systematic evaluation, from 'phase 1' lab experiments to 'phase 4' field tests;
16 establishing and exploring the use of 'living labs' (e.g. [96]) for health and health care.

There is no claim that the two listings of important future research fields above are exhaustive. Although they may look quite different at first glance, these lists can be thought of as being quite consistent. When these suggested research directions take off, they are likely to significantly influence

- other medical disciplines (e.g. in terms of diagnostics and therapeutics),
- human biology (e.g. in terms of implants, including those for healthy persons, suggesting sensor implantation as a new field in human biology, including informatics capability-enhancing extensions),
- computer science and engineering sciences (e.g. in terms of embedded systems and connectivity), and
- empirical sciences (e.g. on new forms of empirical research, there e.g. with respect to living labs).

In addition, the boundaries between disciplines may shift and this may lead to a coalescing of medical informatics and other disciplines [46], with respect to medicine, health sciences, computer science, information sciences (including information system architectures and management), (biomedical) engineering, and (health) economics.

These research directions may also lead to further collaborations. As medical informatics is quite familiar with the practice of inter- and multidisciplinary collaboration (e.g. [12, p. 17, 18]), this would be fully in the tradition of the field.

4.4. *IMIA and the future of medical informatics*

I have already mentioned how IMIA and the international medical informatics community more broadly have influenced the past and the present development of the field. Medical informatics has contributed to the progress of both people's health care in our societies and to the advancement of the sciences. What remains to be asked is, whether IMIA as an association should continue or change its priorities. In referring to [72–80], several points can be highlighted.

IMIA's role for the medical informatics community and in particular for medical informatics research can hardly be underestimated. Continuity is necessary for supporting and stimulating high-quality translational communication, research, education, and practice in medical informatics.

In order to achieve IMIA's objectives it is also important that IMIA continues to serve as the vehicle for international collaboration in a fair, equitable and balanced way, beyond the usual divisions of nations, cultures, political or social structures, looking out for the health and quality of life of the people of the world in a spirit of tolerance and peace.

Summary points

- The aim of this essay is to reflect about medical informatics as a discipline.
- Its main goal is to emphasize some promising future research directions which may become important parts of medical informatics.

Stimulating collaboration in research as always will have to be adapted, in order to capitalize on original and relevant research findings. IMIA's working and special interest groups and IMIA's conferences and publications should continue to play a major role in these scientific exchanges. In particular as many research questions are discussed and treated globally, the international responsibility, which IMIA takes on, is crucial for stimulating and sponsoring the interchange of research.

Stimulating high-quality education in medical informatics might be further improved by giving IMIA academic members a more prominent role. Accreditation on educational programs on a global level is also an important new priority. IMIA's recently published revised recommendations on education [70] had already laid the first milestones in this direction.

The trend towards global activities requires that IMIA continuously emphasizes its independence from specific commercial or political interests, so that it can help in carrying out global projects without bias or conflict of interest. Another responsibility, which might emerge in this context within a globalizing world, is for IMIA itself to organize and run international projects, with WHO being a natural partner.

To conclude, health care is in continuous change just as the sciences are in continuous transformation. Medical informatics as discipline is affected by these changes. Within the sciences, medical informatics plays a critical role in bridging the health and information sciences: the two components of the genomic and translational medicine revolutions, now underway [26,31]. In Section 4.3 it has been mentioned that the boundaries between disciplines may shift and may lead to a coalescing of medical informatics and other disciplines. Such a coalescing might also result in partially integrating or even fully absorbing medical informatics research in other disciplines like biomedicine, health sciences and computer science. This is in my point of view mainly depending on whether medical informatics is willing and successful in taking over itself or whether it is not.

So, to end of this essay, let me recall Reichertz's statement in his last publication [9], where he emphasized that we should not only be prepared for change, but also actively participate in shaping this change. This holds especially for focussing on the relevant and original research fields of tomorrow, building on our research of today and of the past. As it has so often been the case in the past and as it is today, just remaining where we are, is a risk, as we can vividly see from the quote "life punishes those who delay" credited to Mikhail Gorbachev during his visit to East Germany on October 5, 1989. With this in mind, let us actively work on the new research challenges, and let us accept the new responsibilities for medical infor-

matics that science and technology opportunities open up for us.

Acknowledgments

These reflections are strongly influenced by the many discussions with colleagues, mainly, but by no means exclusively, from our scientific community. And, of course, also by many other persons, starting from students and ranging to, e.g., practitioners and policy makers. My acknowledgements go to all of them.

The author cordially thanks Jan Talmon, editor of IJMI, for his valuable comments on this text and for the opportunity to submit this paper to this prestigious journal. As an official journal of IMIA, to which this essay is dedicated, it is just the right place.

Last, but not least, I am grateful to Casimir Kulikowski, with whom I had the pleasure to co-edit seven editions of the IMIA Yearbook of Medical Informatics, for his support and suggestions in editing this manuscript.

REFERENCES

[1] http://www.imia.org, last access: May 22, 2010.
[2] D.F. Sittig, Grand challenges in medical informatics? J. Am. Med. Inform. Assoc. 1 (1994) 412–413 (discussion and comments in 2004 at last access: May 22, 2010) http://baseportal.com/cgi-bin/baseportal.pl?htx=/deanforrest/GrandChallenges.
[3] R.B. Altman, Informatics in the care of patients: ten notable challenges, West J. Med. 166 (1997) 118–122.
[4] R. Haux, Aims and tasks of medical informatics, Int. J. Med. Inform. 44 (1997) 9–20 (discussion, pp. 21–87).
[5] R.A. Greenes, N.M. Lorenzi, Audacious goals for health and biomedical informatics in the new millennium, J. Am. Med. Inform. Assoc. 5 (1998) 395–400.
[6] S. Kay, Health informatics: challenges to progress, Methods Inf. Med. 38 (1999) 225–227.
[7] D.A.B. Lindberg, Medicine in the 21st century: global problems, global solutions, Methods Inf. Med. 41 (2002) 235–236.
[8] P.L. Reichertz, Medical informatics—fiction or reality? Methods Inf. Med. 19 (1980) 11–15.
[9] P.L. Reichertz, Preparing for change: concepts and education in medical informatics, Comput. Methods Programs Biomed. 25 (1987) 89–102.
[10] R.A. Greenes, E.H. Shortliffe, Medical informatics, an emerging academic discipline and institutional priority, J. Am. Med. Inform. Assoc. 263 (1990) 1114–1120.
[11] D.J. Protti, J.H. van Bemmel, R. Gunzenhäuser, et al., Can health/medical informatics be regarded as a separate discipline? Methods Inf. Med. 33 (1995) 318–326.
[12] J.H. van Bemmel, Medical informatics, art or science? Methods Inf. Med. 35 (1996) 157–172 (discussion, pp. 173–201).
[13] V. Maojo, C.A. Kulikowski, Bioinformatics and medical informatics: collaboration on the road to genomic medicine? J. Am. Med. Inform. Assoc. 10 (2003) 515–522.
[14] V. Maojo, C. Kulikowski, Medical informatics and bioinformatics: integration or evolution through scientific crises? Methods Inf. Med. 45 (2006) 474–482.
[15] C.A. Kulikowski, Introducing Kuhn et al.'s paper "Informatics and medicine—from molecules to populations" and invited papers on this special topic, Methods Inf. Med. 47 (2008) 279–282.
[16] K.A. Kuhn, A. Knoll, H.W. Mewes, M. Schwaiger, et al., Informatics and medicine—from molecules to populations, Methods Inf. Med. 47 (2008) 283–295.
[17] R.B. Altman, R. Balling, J.F. Brinkley, E. Coiera, et al., Commentaries on "Informatics and medicine: from molecules to populations", Methods Inf. Med. 47 (2008) 296–317.
[18] J.H. van Bemmel, Medical informatics is interdisciplinary avant la lettre, Methods Inf. Med. 47 (2008) 318–321.
[19] B. Blum (Ed.), A framework for medical information science, Med. Inform. 9 (1984) 167–313.
[20] J.H. van Bemmel, The structure of medical informatics, Med. Inform. 9 (1984) 175–179.
[21] M.S. Blois, Medical information science as 'science', Med. Inform. 9 (1984) 181–183.
[22] E.H. Shortliffe, The science of biomedical computing, Med. Inform. 9 (1984) 185–193.
[23] J.H. van Bemmel, M.A. Musen (Eds.), Challenges for medical informatics as an academic discipline, Methods Inf. Med. 41 (2002) 1–63.
[24] J.L. Talmon, A. Hasman, Medical informatics as a discipline at the beginning of the 21st century, Methods Inf. Med. 41 (2002) 4–7.
[25] M.A. Musen, Medical informatics: searching for underlying components, Methods Inf. Med. 41 (2002) 12–19.
[26] C.A. Kulikowski, The micro-macro spectrum of medical informatics challenges: from molecular medicine to transforming health care in a globalizing society, Methods Inf. Med. 41 (2002) 20–24.
[27] F. Martin-Sanchez, V. Maojo, G. Lopez-Campos, Integrating genomics into health information systems, Methods Inf. Med. 41 (2002) 25–30.
[28] M. Stefanelli, Knowledge management to support performance-based medicine, Methods Inf. Med. 41 (2002) 36–43.
[29] J. van der Lei, Closing the loop between clinical practice, research, and education: the potential of electronic patient records, Methods Inf. Med. 41 (2002) 51–54.
[30] P. Knaup, H. Dickhaus (Eds.), Perspectives of medical informatics: advancing health care requires interdisciplinarity and interoperability. Special topic on the occasion of the 35th anniversary of the Heidelberg/Heilbronn curriculum of medical informatics, Methods Inf. Med. 48 (2009) 1–75.
[31] C.A. Kulikowski, C.W. Kulikowski, Biomedical and health informatics in translational medicine, Methods Inf. Med. 48 (2009) 4–10.
[32] H. Handels, J. Ehrhardt, Medical image computing for computer-supported diagnostics and therapy. Advances and perspectives, Methods Inf. Med. 48 (2009) 11–17.
[33] H. Witte, M. Ungureanu, C. Ligges, D. Hemmelmann, et al., Signal informatics as an advanced integrative concept in the framework of medical informatics. New trends demonstrated by examples derived from neuroscience, Methods Inf. Med. 48 (2009) 18–28.
[34] S. Koch, M. Marschollek, K.H. Wolf, M. Plischke, et al., On health-enabling and ambient-assistive technologies. What has been achieved and where do we have to go? Methods Inf. Med. 48 (2009) 29–37.
[35] H.U. Prokosch, T. Ganslandt, Perspectives for medical informatics. Reusing the electronic medical record for clinical research, Methods Inf. Med. 48 (2009) 38–44.
[36] C. Ohmann, W. Kuchinke, Future developments of medical informatics from the viewpoint of networked clinical research, Methods Inf. Med. 48 (2009) 45–54.

[37] K.P. Pfeiffer, Future development of medical informatics from the viewpoint of health telematics, Methods Inf. Med. 48 (2009) 55–61.
[38] A. Winter, The future of medical informatics. Some perspectives of intra- and inter-institutional information systems, Methods Inf. Med. 48 (2009) 62–65.
[39] ISTAG, Report on grand challenges in the evolution of the information society, Luxemburg: Office for Official Publications of the European Communities, 2004. http://cordis.europa.eu/fp7/ict/istag/reports_en.html, last access: May 22, 2010.
[40] W.W. Stead, H.S. Lin (Eds.), Computational Technology for Effective Health Care: Intermediate Steps and Strategic Directions, U.S. National Academic Press, Washington (DC), 2009.
[41] J.H. van Bemmel, A changing world of grand challenges, Int. J. Med. Inform. 44 (1997) 53–55.
[42] A. Hasman, et al., A systematic view on medical informatics, Comput. Methods Programs Biomed. 51 (1996) 131–139.
[43] W. Hersh, A stimulus to define informatics and health information technology, BMC Med. Inform. Decision Making 9 (2009) 24.
[44] N.M. Lorenzi, 40 years of IMIA: shaping medical informatics worldwide, Yearb. Med. Inform. (2007) 163–164.
[45] M.J. Ball, J.H. van Bemmel, S. Kaihara, IMIA presidential retrospectives on medical informatics, Yearb. Med. Inform. (2007) 165–175.
[46] C.A. Kulikowski, IMIA: coalescing medical informatics worldwide for 40 years, Yearb. Med. Inform. (2007) 176–185.
[47] S.A. Huesing, IMIA—a 40 year organizational overview, Yearb. Med. Inform. (2007) 186–191.
[48] H.E. Peterson, M. Hutter, IMIA's publication history, Yearb. Med. Inform. (2007) 192–196.
[49] M.F. Collen, Origins of medical informatics, West. J. Med. 145 (1986) 778–785.
[50] P.L. Reichertz (Ed.), Minutes of the invitational workshop on goals, contents and methods for education in medical informatics, Yearb. Med. Inform. (2004) 210–219 (in German, translated by J.R. Moehr).
[51] J.R. Moehr, The quest for identity of health informatics and for guidance to education in it—the German Reisensburg conference of 1973 revisited, Yearb. Med. Inform. (2004) 201–210.
[52] http://www.imiapubs.org and http://www.schattauer.de/de/magazine/uebersicht/zeitschriften-a-z/imia-yearbook/, last access: May 22, 2010.
[53] M.F. Collen, Fifty years in medical informatics, Yearb. Med. Inform. (2006) 174–179.
[54] H.E. Peterson, From punched cards to computerized patient records: a personal journey. IMIA Yearbook of Medical Informatics, Yearb. Med. Inform. 2006 (2006) 180–186.
[55] R.S. Ledley, L.B. Lusted, Reasoning foundations of medical diagnosis; symbolic logic, probability, and value theory aid our understanding of how physicians reason, Science 130 (3366) (1959) 9–21.
[56] P.L. Reichertz, Hospital information systems – past, present, future – key-note address during 'Medical Informatics Europe 84', 5th Congress of the European Federation for Medical Informatics, Brussels, September 10–13, 1984. Republished in Int. J. Med. Inform., 75 (2006) 282–299.
[57] J.C. Pagès, A.H. Levy, F. Grémy, J. Anderson (Eds.), Meeting the Challenge: Informatics and Medical Education, North Holland, Amsterdam, 1983.
[58] J.L. Willems, P. Arnaud, J.H. van Bemmel, P.J. Bourdillon, et al., Establishment of a reference library for evaluating computer ECG measurement programs, Comput. Biomed. Res. 18 (1985) 439–457.
[59] J.L. Willems, C. Abreu-Lima, P. Arnaud, J.H. van Bemmel, et al., The diagnostic performance of computer programs for the interpretation of electrocardiograms, N. Engl. J. Med. 325 (1991) 1767–1773.
[60] IMIA, Minutes of the General Assembly 1999, Washington, DC, November 11, 1999.
[61] Recommendations of the International Medical Informatics Association (IMIA) on education in health medical informatics, Methods Inf. Med. 39 (2000) 267–277.
[62] R. Haux, P.J. Murray, On IMIA's international activities in health and biomedical informatics education, Methods Inf. Med. 49 (2010) 305–309.
[63] R.M. Gardner, T.A. Pryor, H.R. Warner, The HELP hospital information system: update 1998, Int. J. Med. Inform. 54 (1999) 169–182.
[64] J.P. Deshazo, D.L. Lavallie, F.M. Wolf, Publication trends in the medical informatics literature: 20 years of "Medical Informatics" in MeSH, BMC Med. Inform. Decision Making 9 (2009) 7.
[65] A. Winter, R. Haux, E. Ammenwerth, B. Brigl, N. Hellrung, F. Jahn, Health Information Systems—Architectures and Strategies, Springer, New York, 2010 (in print).
[66] U.S. Census Bureau, Information and Communication Technology Survey, 2010 (last access: May 22, 2010) http://www.census.gov/csd/ict.
[67] European Communities, Accelerating the development of the eHealth market in Europe. Office for Official Publications of the European Communities, Luxembourg, 2007 (last access: May 15, 2010) http://ec.europa.eu/information_society/activities/health/downloads/index_en.htm.
[68] G.F. Anderson, B.K. Frogner, R.A. Johns, U.E. Reinhardt, Health care spending and use of information technology in OECD countries, Health Aff. (Millwood) 25 (2006) 819–831.
[69] A. Geissbuhler, R. Haux, S.Y. Kwankam, Towards health for all: WHO and IMIA intensify collaboration. Joint Communiqué during Medinfo 2007 in Brisbane, Methods Inf. Med. 46 (2007) 503–505.
[70] J. Mantas, E. Ammenwerth, G. Demiris, A. Hasman, et al., IMIA Recommendations on Education Task Force. Recommendations of the International Medical Informatics Association (IMIA) on education in biomedical and health informatics. First revision, Methods Inf. Med. 49 (2010) 105–120.
[71] J. Talmon, E. Ammenwerth, J. Brender, N. de Keizer, P. Nykänen, M. Rigby, STARE-HI–statement on reporting of evaluation studies in health informatics, Int. J. Med. Inform. 78 (2009) 1–9, Reprint in Yearb. Med. Inform. (2009) 23–31.
[72] N.M. Lorenzi, Towards IMIA 2015–the IMIA strategic plan, Yearb. Med. Inform. (2007) 1–5.
[73] P. Murray, R. Haux, N. Lorenzi, Let a thousand flowers bloom: transition towards implementation of the IMIA strategic plan, Methods Inf. Med. 46 (2007) 625–628.
[74] P.J. Murray, The IMIA strategic plan–towards IMIA 2015, Yearb. Med. Inform. (2008) 7–15.
[75] R. Haux, Preparing for change: medical informatics international initiatives for health care and biomedical research, Comput. Methods Programs Biomed. 88 (2007) 191–196.
[76] R Haux, Health care and informatics: on IMIA's opportunities and responsibilities in its 5th decade, Yearb. Med. Inform. (2008) 1–6.
[77] R. Haux, J. Howe, M. Marschollek, M. Plischke, K.H. Wolf, Health-enabling technologies for pervasive health care: on services and ICT architecture paradigms, Inform. Health Soc. Care 33 (2008) 77–89.

[78] R Haux, IMIA and its members: on balancing continuity and transition in biomedical and health informatics, Yearb. Med. Inform. (2009) 1–6.
[79] R. Haux, M.J. Ball, From theory into practice: bridging the clinical informatics divide!, Appl. Clin. Inf. (2009) 8–11.
[80] R. Haux, IMIA: the global informatics perspective for good health, Yearb. Med. Inform. (2010) 1–5.
[81] M.J. Schuemie, J.L. Talmon, P.W. Moorman, J.A. Kors, Mapping the domain of medical informatics, Methods Inf. Med. 48 (2009) 76–83.
[82] Modeling in biomedical informatics: pastime or necessity? A dialogue on lessons from the past and directions for the future, Artif. Intell. Med. 38 (2006) 319–326.
[83] A. Hasman, R. Haux, Modeling in biomedical informatics: an exploratory analysis (part 1), Methods Inf. Med. 45 (2006) 638–642.
[84] A. Hasman, R. Haux, Modeling in biomedical informatics: an exploratory analysis (part 2), Int. J. Med. Inform. 76 (2007) 96–102.
[85] A. Geissbuhler, C.O. Bagayoko, O. Ly, The RAFT network: 5 years of distance continuing medical education and tele-consultations over the Internet in French-speaking Africa, Int. J. Med. Inform. 76 (2007) 351–356.
[86] P. Teilhard de Jardin, Le phénomè humain, Éditions du Seuil, Paris, 1955.
[87] http://www.un.org/en/development/devagenda/information.shtml, last access: May 22, 2010.
[88] International Telecommunication Union, National e-Strategies for development: global status and perspectives, 2010 (last access: May 22, 2010) http://www.itu.int/ITU-D/cyb/estrat/estrat2010.html.
[89] J.C. Healy, The WHO eHealth Resolution–eHealth for all by 2015, Methods Inf. Med. 46 (2007) 2–4.
[90] http://www.who.int/goe/en, last access: May 22, 2010.
[91] M. Kay, J. Santos, Report on the World Health Organization Global Observatory for eHealth strategic planning workshop, Methods Inf. Med. 47 (April) (2008) 381–387.
[92] World Health Organization, Building foundations for eHealth, progress of member states. Report of the WHO Global Observatory for eHealth, WHO, Geneva, 2006 (last access: May 22, 2010) http://www.who.int/goe/publications/bf_FINAL.pdf.
[93] United Nations, Department of Economic and Social Affairs, Population Division. World Population Ageing 2009, United Nations, New York, 2009 (last access: May 22, 2010) http://www.un.org/esa/population/publications/WPA2009/WPA2009_WorkingPaper.pdf.
[94] R. Haux, Health information systems–past, present, future, Int. J. Med. Inform. 75 (2006) 268–281.
[95] R. Haux, E. Ammenwerth, W. Herzog, P. Knaup, Health care in the information society. A prognosis for the year 2013, Int. J. Med. Inform. 66 (2002) 3–21 (discussion 23–120).
[96] European Commission—Information Society and Media, Living labs for user-driven open innovation—an overview of activities, Luxembourg: Office for Official Publications of the European Communities, 2008. http://ec.europa.eu/information_society/activities/livinglabs/docs/brochure_jan09_en.pdf, last access (to January 2009 edition): June 6, 2010.