

# Biomedical Informatics – A Confluence of Disciplines?

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## Keywords

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## Summary

**Background:** Biomedical informatics is a broad discipline that borrows many methods and techniques from other disciplines.

**Objective:** To reflect a) on the character of biomedical informatics and to determine whether it is multi-disciplinary or inter-disciplinary; b) on the question whether biomedical informatics is more than the sum of its supporting disciplines and c) on the position of biomedical informatics with respect to related disciplines.

**Method:** Inviting an international group of experts in biomedical informatics and related disciplines on the occasion of the 50th anniversary of *Methods of Information in Medicine* to present their viewpoints.

**Results and Conclusions:** This paper contains the reflections of a number of the invited experts on the character of biomedical informatics. Most of the authors agree that biomedical informatics is an interdisciplinary

field of study where researchers with different scientific backgrounds alone or in combination carry out research. Biomedical informatics is a very broad scientific field and still expanding, yet comprised of a constructive aspect (designing and building systems). One author expressed that the essence of biomedical informatics, as opposed to related disciplines, lies in the modelling of the biomedical content. Interdisciplinarity also has consequences for education. Maintaining rigid disciplinary structures does not allow for sufficient adaptability to capitalize on important trends nor to leverage the influences these trends may have on biomedical informatics. It is therefore important for students to become aware of research findings in related disciplines. In this respect, it was also noted that the fact that many scientific fields use different languages and that the research findings are stored in separate bibliographic databases makes it possible that potentially connected findings will never be linked, despite the fact that these findings were published. Bridges between the sciences are needed for the success of biomedical informatics.

## 1. Introduction

“We are not students of some subject matter, but students of problems. And problems may cut right across the borders of any subject matter or discipline.” – Karl Popper

From June 9 to 11, 2011, a symposium celebrating the 50th anniversary of *Methods of Information in Medicine* (MIM) was held in Heidelberg, Germany. A broad spectrum of Biomedical Informatics (BMI) researchers attended, in addition to members of the MIM editorial board. During this event position papers were presented reflecting on the opportunities, challenges and priorities implied by the symposium theme, “Biomedical Informatics: Confluence of Multiple Disciplines”.

This symposium organized by MIM was very timely. Our specialty, Biomedical Informatics, is at a crossroad. Information technology has become pervasive in all aspects of healthcare. It is present in microscopes; in DNA sequencers; in chips for bacteriology; in all types of devices, from pacemakers to MRIs; it is the cornerstone of running hospitals and building community networks. Building the virtual physiological human would not be thinkable without information technology. Advances in DNA sequencing from the field of biotechnology can make it possible to know the whole genome of a patient at a reasonable cost and time in the near future. This opens the door to the practice of a more

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personalized medicine. Beyond this, advances from physics, chemistry and engineering are facilitating new ways of intervention in the human body to repair or replace parts of it that have failed to perform its function properly, either by accident, disease or aging. These developments are shaping the areas known as nanomedicine and regenerative medicine. Similar advances are occurring in other areas such as sensors or mobile devices. It is time to reflect on the character of BMI, which may build on this rapidly expanding information technology infrastructure. Is BMI a multidisciplinary field (involving researchers with different backgrounds) or is it an interdisciplinary one, having its own methods and theories?

Biomedical informatics is a discipline having biology and medicine as its domains of study. Several names for related BMI sub-disciplines, usually describing different application areas, are in use, for example: bioinformatics, medical informatics, nursing informatics, clinical informatics, and health informatics. Researchers in the field apply methods coming from very diverse areas like physics, electrical and mechanical engineering, computer science, statistics, epidemiology, sociology, and cognitive science. Also the background of researchers in biomedical informatics varies considerably. Given this diversity, the question can therefore be raised: What is the essence of the discipline? More specifically, what kind of disciplinary characterizes BMI? Is it:

- Intra-disciplinary (work within a single discipline);
- Cross-disciplinary (viewing one discipline from the perspective of another);
- Multi-disciplinary (each discipline provides a different perspective on a problem in an additive way); or,
- Interdisciplinary (integration of knowledge, concepts, tools, and rules of investigation from the disciplines that are combined in such a way that the resulting understanding is greater than simply the sum of its disciplinary parts)?

The following viewpoints aim to answer the question of whether biomedical informatics is interdisciplinary (with its own methodology and theories in addition to

the knowledge that it borrows from other disciplines) or multidisciplinary (a mixture of the contributing sciences to form a coalescent discipline in its own right). The position of biomedical informatics with respect to other related disciplines is also discussed. Finally, consequences for education in biomedical informatics are described.

## 2. Viewpoint 1 – Biomedical Informatics: A Boundary Discipline

### 2.1 Definition of Biomedical Informatics

Biomedical informatics is commonly referred to as a science between medicine and information science. This view suggests that there are two main basic and large disciplines, information science and technology on one side and medicine – or health science – on the other; and medical informatics is just a thin surface where these two large fields touch each other. Another common view is that biomedical informatics is nothing other than just applying information technology (using computers) in health systems and the medical domain.

Both views appear to be superficial. We cannot find one universally accepted definition of biomedical informatics in the literature. Interestingly, Chen et al. [1] do not give a definition for biomedical informatics in their textbook, but emphasize the central role of representation of biomedical knowledge when they describe the field. Another textbook, written by Enrico Coiera [2] states:

*“If physiology literally means ‘the logic of life’, and pathology is ‘the logic of disease’ then health informatics is the logic of health-care.”*

And a bit later: *“It is now hard to imagine just how controversial the introduction of theory and experimental method into medicine once was. Then, it was strongly opposed by the views of empiricists, who believed that observation, rather than theoretical conjecture, was the only basis for the rational practice of medicine.”*

*With this perspective, it is almost uncanny to hear again the old empiricist’s argument*

*that ‘healthcare is an art’, and not a place for unnecessary speculation or formalisation.”*

We are thus led to think that this last word, ‘formalisation’ is the main point to understand the essence of biomedical informatics. Just to avoid any misunderstanding, let us make clear what is meant by formalisation. A formal language is a defined, finite set of symbols and a finite set of syntactic rules that should be met when we compose certain series of symbols from the symbol set. Beyond that, in a formal system we have certain ‘canonical’ sentences (axioms) and certain transformation rules that could be applied to axioms (and already proven theorems) in order to get new theorems. ‘Formalisation’ then means that we strive to represent phenomena of a certain domain by a formal system.

### 2.2 The Problem of Complexity

The result of formalisation is a *structure* of entities and relations. On the other hand a formalisation is a model of a domain of reality. Up to a certain limit axioms and theorems proven in a formal system correspond with some truth in the represented domain of reality. The structure of entities and relations forms a system. According to Ludwig von Bertalanffy, a *“system is a complex of interacting parts”* [3]. Biomedical systems – be it either a yeast cell or the health care system of a country – are enormously complex; and usually the “parts” are systems themselves. So what results is a complex of interacting complex systems. Let us call it multi-level complexity. How can we study or understand such systems? Bertalanffy’s starting point was that the conventional – and in a certain sense quite effective – scientific approach is the *analytic* way: we can decompose our systems into isolated pairs of entities, and one single relation between each pair. But then we have to ‘reconstruct’ the *whole* system from these pair-wise relations, and this fails quite often. Let us mention some examples.

In SNOMED CT, the concept *beer* is defined as a kind of alcohol (alcoholic beverage). This seems to be a fair statement if we consider just these two entities. But then *alcohol free beer* is considered in SNOMED CT as a kind of beer, which is again reason-

able if we look at this relation in an isolated view. However, putting these two statements together results in a comical confusion (*alcohol free beer* is a kind of *alcoholic beverage*). Another good example is the case of drug interactions. It is very clear that a database of interactions of drug *pairs* is not necessarily suitable to predict interactions that exist between triples of drugs. A PubMed search for “Drug interactions” retrieved 78,706 publications, while the search term “Triple drug interactions” retrieved only 634 and “Multiple drug interactions” only 37. This demonstrates that it is still true, what Fitzsimmons wrote 1989 [4]: “A large body of literature describes the potential interactions between two pharmacologic agents. However, little information exists regarding potential interactions between multiple agents.”

Bertalanffy introduced the idea of a systemic view instead of an analytic approach to complex problems. At his time – in the seventies – this idea led to certain mysticism and received serious criticism.

The problem of complexity – the difficulty of understanding a whole system from facts and rules of pair-wise behaviour of its constituents – is increasingly addressed today in the general biomedicine literature [5, 6], but perhaps not fully addressed within the realm of biomedical informatics.

### 2.3 Back to the Idea of Boundary Discipline

Summing up these considerations, we cite Coiera again: “*Health informatics thus is as much about computers as cardiology is about stethoscopes.*”

Biomedical informatics really lies at the boundary of the sciences and cannot be practiced without use of information technology. But the real contribution of biomedical informatics is its quest to organise the unimaginably complex and huge amount of knowledge that is at the disposal of a modern physician. This knowledge arises from a number of different sciences from physics and biochemistry to social sciences and psychology and law. But a unified formalisation of this knowledge and dealing with the complexity – avoiding the

trap both of reductionism and mysticism – will be the challenge of the coming decades of our profession.

## 3. Viewpoint 2 – Confluence of Multiple Disciplines – Converging Sciences

Information technology is ubiquitous. Never before has a technology been so ubiquitous that it had to be shared by everybody, every scientist, but also all other actors, patients, physicians, governance, policy makers, in short: everybody.

Numerous aspects have already been discussed, such as the digital divide, education, interoperability, sustainability, amongst others; this ubiquitous and global growth leads to two very important challenges:

- On one side, there is the growth of a heterogeneous lattice of disconnected information, knowledge, objects and actions that is mostly not reachable with formal tools. With the increasing amount of information, this lattice is growing and accumulates increasing incoherence. New paradigms will have to be found in order to allow and to support the convergence and the smooth connection of all these pieces of information. This is usually named interoperability, technical and semantic. In fact, it is much more than that, as it has to be able to represent the meanings in time. With the evolution of human knowledge, meanings are changing, and it will be increasingly important to be able to retrieve the “meanings at that time”.
- On the other side, there are humans. One of the difficult challenges to face is the convergence, sometimes the confluence, of disciplines. Unfortunately, many disciplines are strongly separated one from the others. They have specific schools, schools of thought, cultures, visions of the world, research methodologies, vocabularies, journals and publication databases. For example, many innovations in mathematics and statistics will not show up in MEDLINE,

nor will potentially related findings from quantum physics, business, politics, or law. And these are precisely some of the converging disciplines that make sense for the aforementioned lattice.

Medicine has always had a special place in sciences: At the intersection of all sciences, it has long been considered more as an art rather than a specific science. The recent history of the evolution of medicine has been revolutionized with the emergence of new fields, such as signal processing, biomaterials, biogenetics, nanotechnologies, cybernetics but also economics, human factors, humanities to name a few. As glue for all these intersecting fields, there is information, knowledge and communication. This is probably one of the greatest opportunities for information science in medicine, by bringing the chance to escape all dogmas and playing the major role of a “no man’s land” where all sciences can meet, can share, merge and leverage each other. As a recent example of this evolution: Erwin Schrödinger stated that the molecular scale was the pertinent level of description in biology and that quantum physics would not apply to living organisms [7]. However, these last years, several discoveries suggest that various quantum behaviours do have an important effect in living organisms [8], such as the performance of photosynthetic organisms to capture photons [9] or the mechanism of enzymatic catalysis activity of which the precise origin long remained unexplained [10]. There are hints now suggesting that, at least for some part, this effect would be mediated by a quantum tunnel effect [11].

Quantum physics is just another of these numerous aspects of human knowledge improving our understanding of life and medicine. In order to be able to transform and leverage all these information sources into knowledge, an improved approach to medical information management has to be created.

As a consequence, the scientific literature is literally exploding. However, transdisciplinary literature retrieval remains very difficult: major domains, such as physics, mathematics, economics or life sciences have their own databases. Identify-

ing important papers is increasingly difficult, and tools such as the impact factor not really relevant [12], especially when it comes to transversal research. It becomes increasingly difficult to follow the information published, even in narrow domains. There is therefore an increasing amount of unused and unknown knowledge hidden in the literature. Aggregating all databases or building meta-indexes covering all disciplines and supporting easy cross-domain queries will become increasingly important. Developing intelligent tools to support literature searches and knowledge discovery should be massively supported [13]. Otherwise, more and more research will be repeated and potentially connected findings never linked together, despite the fact that they have been published.

In conclusion, the confluence of disciplines in the highly complex field of biomedical informatics is facing new challenges, but is also granting new fields of competences. Important challenges should be clearly identified and addressed in cooperative, collaborative ways, bringing together all fields of knowledge and disciplines involved, in order to find new and innovative solutions.

## 4. Viewpoint 3 – Informatics: The Discipline that Cares About the Content

### 4.1 Emerging Forever

Bernstam and colleagues [14] recently joked that “Biomedical informatics has been an ‘emerging field’ for decades” (p 104). Indeed, for as long as there have been workers in biomedical informatics, there have been members of our community who have tried to define exactly what biomedical informatics is [15]. Each decade brings new attempts to define the field in a way that conveys the essence of the discipline while remaining maximally inclusive of all our colleagues. The International Medical Informatics Association Task Force on Education in Biomedical and Health Informatics [16] and the Core Competencies working group of the American Medical Informatics Associ-

ation’s Academic Forum [17] have offered extremely useful guidance. Still, *biomedical informatics* generally remains defined operationally by its practitioners. Until our community can achieve consensus on what makes our theory and practice unique – and can stop defining itself in work in terms of other academic disciplines – biomedical informatics will continue to be perceived as an emerging field, and we will suffer from our perpetual identity crisis.

Like all of us who care about our discipline, I believe that biomedical informatics needs to clarify its own set of principles and theories [18]. Informatics is not the application of computer science, image processing, and statistics to a particular domain. Rather, informatics is a primary field of study that may be targeted toward a wide variety of disciplines (health care and the life sciences being particularly important to us). What sets informatics apart from computer science and from other potentially confluent fields is a matter of priorities: Ours is the discipline that cares about the content ([18] p 18).

### 4.2 Caring about the Content

Contemporary work in informatics is enriched by complementary work in computer science, electrical and mechanical engineering, cognitive science, and a host of other fields. It is hard to conceive of the development of clinical imaging systems without reliance on a healthy dose of electrical engineering; work in electronic patient records builds naturally on activity in computer science and human factors. There is a reason, however, that it is hard to imagine a computer scientist, for example, designing an electronic patient record system single-handedly. Computer scientists focus on issues such as computation, data storage, and networking. Computer scientists assume that the formal parameters of algorithms will be bound to appropriate values, but they often do not give much thought to where those bindings have to come from. Workers in informatics, on the other hand, certainly may worry about issues such as computational efficiency and network latency, but those are not their primary concerns. Workers in informatics

care about whether the patient record has been modelled correctly, whether the model is extensible, and whether the model is usable. The emphasis in biomedical informatics is on whether models of the healthcare enterprise, of patients and their illnesses, and of providers and their work preferences are sufficiently robust to enable comprehensive management of patient care. It is not that workers in biomedical informatics are oblivious to problems of computation and data storage, but rather that informaticians are chiefly invested in modelling the biomedical content.

It is now widely accepted that static domain distinctions are properly modelled in terms of ontologies that define the entities in an application area, the properties of those entities, and the relationships among them [19, 20]. Building reusable ontologies has become a major focus of work in informatics. From the Gene Ontology to SNOMED-CT, from the National Drug File Reference Terminology to the National Cancer Institute Thesaurus, standard reusable ontologies provide the static content descriptions required to build current-generation information systems. Even when there are no standard ontologies available to capture the content descriptions needed to design an application, workers in informatics are prepared to create the new, sometimes informal ontologies required to drive the development of novel systems.

Modelling biomedical systems requires more than just the modelling of static domain knowledge, however. The systems that we build solve tasks in the world, from bibliographic retrieval to clinical image analysis to decision support – and all these tasks entail some sort of algorithmic data processing. Each task that our systems carry out must be automated using an algorithmic procedure. Workers in informatics have come to model procedural tasks in terms of problem solvers that transform data inputs into data outputs. Such transformations must be achieved by an explicit, modular algorithm that operates to solve the task at hand. Because an algorithm may entail a set of subtasks, our procedural models often reflect task decomposition [21], where an overall task may be construed using a model of problem solving that specifies subtasks that in turn may be

addressed by yet other models of problem solving, recursively. Developers often create quite complex task-decomposition models to describe intricate problem-solving behaviour in biomedicine [22].

In the past decade, both task-decomposition analysis and the modelling of tasks using abstract models of problem solving have become almost routine. In part, the advent of the Model-Driven Architecture (MDA) approach promoted by the Object Management Group has made this kind of procedural modelling commonplace [23]. More importantly, the popularization of service-oriented architectures and Web services in the software-engineering community has provided the hooks that make it straightforward for system builders to translate their abstract models of problem solving into implemented services that can be invoked by software applications in standardized ways over the Internet [24].

Domain ontologies and models of problem-solving methods provide building blocks that enable workers in biomedical informatics to construct models of both the static and the procedural elements of application systems. The informatics community does not in any way own these modelling constructs. Computer scientists and other engineers certainly seek to incorporate models based on these primitives into their professional activity. Nevertheless, it is the members of the informatics community who dedicate their professional work to getting the underlying models right.

### 4.3 Toward a More Informed Style of Collaboration

When I first joined the Stanford faculty and attempted to explain to a colleague in the Department of Anthropology what I did for a living, he replied immediately: “So you’re a ‘broker’. You help the computer people and the medical people to understand one another!” I tried hard to make the case that there was a particular contribution that I made to the process of system building that went beyond the mere translation of jargon, but I was hard pressed to explain it. Years later, I remain convinced that the essence of biomedical informatics

lies in the modelling of both static domain knowledge and of processes. Workers in informatics are not passive translators who broker information among different, confluent professional groups; they are the active creators *de novo* of the models that form the basis of our inventions to process, communicate, and apply biomedical knowledge and data. Workers in informatics are indeed the professionals who care about the content. They are the theorists and the practitioners who have the unique skills needed to render domain knowledge and data in a form where they can be examined, studied, and processed computationally.

This perspective on modelling is motivated by much more than a desire to carve out “turf” or to make arbitrary distinctions among the diverse collaborators who frequently join forces with us to tackle complex projects. Understanding the particular skills of the informatics community helps us to clarify how informaticians can best contribute to the kinds of large-scale collaborative initiatives that often represent our most visible contributions to science and engineering. Most important, elucidating the core modelling competencies of workers in biomedical informatics can provide important guidance to our informatics training programs [16, 17], to our textbooks and scientific publications, and to the way that we view ourselves as a profession.

## 5. Viewpoint 4 – Interdisciplinarity Offers New Opportunities for Research Innovation

As mentioned in the introduction, biomedical informatics (BMI) is broadening its reach to interact with disciplines previously very far from its scope. The thesis that I (FJM-S) defend in this viewpoint is that one of the main challenges for our discipline in the coming years is to facilitate and promote such interdisciplinary work.

### 5.1 The Need for a Precise Definition of the BMI Field

The scientific community involved in areas related to BMI is becoming extremely rich and complex. Not only hospitals and biomedical research centres, but other institutes and networks as well as many companies develop part or all of their activity in the area of biomedicine. There are also many initiatives that promote eResearch (several of them in biomedicine) and eHealth projects.

This context, which is highly multidisciplinary, one might consider as an opportunity for innovation in research in BMI. From this perspective, we need to define very precisely the area in which we work and communicate it appropriately to all parties. This contributes to avoid misunderstandings and focuses expectations on what we really can do. The diagram shown in ►Figure 1 could be useful in this regard.

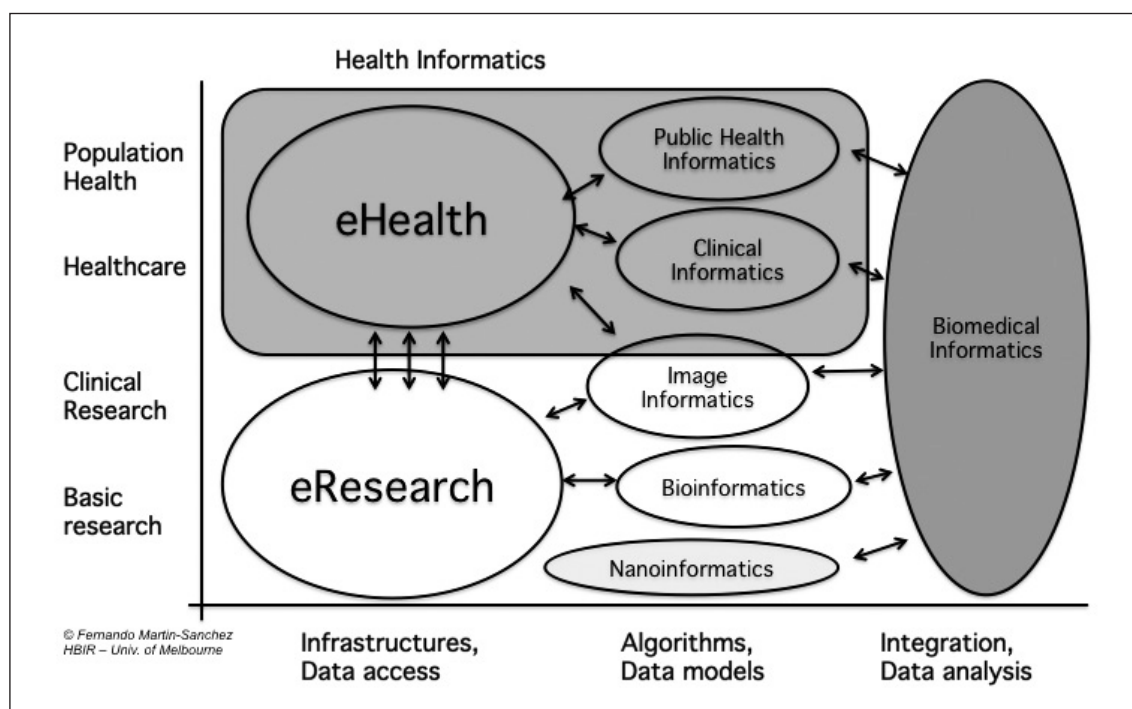
### 5.2 The Challenge of Interdisciplinarity

If we consider that a discipline is not defined by the object of study, but by how we look at it, then in Medicine, we look to the human body and depending on the perspective we can find connections with other disciplines, for example:

- Physics (Radiation, ultrasound, materials, electrical signals)
- Chemistry (Molecules)
- Biology (Genes and proteins)
- Histology (Images from cells and tissue)
- Anatomy (Organs and the whole body)
- Clinical Sciences (Symptoms, effect of treatments)
- Psychology (Behaviour, cognitive signs)
- Public Health (Aggregate data from populations, environmental factors)

From this angle, a new area, nanotechnology, offers new methods to look at the human body with unprecedented detail. Thus, new DNA ultrasequencers based on nanospheres, let us look at the genotype of a person, new transdermal nanosensors allow us to evaluate aspects of the phenotype such as glucose level monitoring and

**Fig. 1**  
Map showing the different scope and technological focus of several disciplines related with HBI. The three areas in gray represent the areas of interest of our Department.



different bionanosensors can provide data on environmental factors affecting a person or population (radiation, contamination, toxicity) [25]. It seems plausible that these new developments could enable further progress in both the biomedical and informatics fields.

Although there are various ways to represent the subspecialties that are covered by the area of BMI the one that uses different levels of organization of nature seems especially appropriate to address the issue of interdisciplinarity. As described elsewhere, the sub-disciplines (translational bioinformatics, image informatics, clinical informatics, public health informatics) are areas specialized in processing information at different levels, from the molecule to the population (and arguably from the particle on the lowest level if we include nanoinformatics) [26].

Interdisciplinarity is the concept that really represents an opportunity for innovation in research in BMI [27]. Fortunately, interdisciplinarity can be measured, mapped, and compared [28]. It is becoming increasingly clear that to advance our knowledge on the causes of disease and health and to find new diagnostic and therapeutic solutions we can not keep on

just dividing the problem in pieces and parcelling them to specialists (e.g., bioinformaticians or clinical informaticians). The problems (i.e., diseases) are continuous entities and partial solutions must be interrelated, hence the need to promote actual interdisciplinary work. Each specialty is important, but someone has to look at the whole [29, 30]. Could this be a role for the next generation of BMI scientists?

### 5.3 Impact on Education

The challenges related with the promotion of interdisciplinarity will also have an impact on the design of programs for the education of future scientists in BMI. We should try to promote training in skills that can be used for these purposes. For example, to enable interdisciplinarity, we should encourage the use of social networks to interact with other communities. It is also important to participate in multidisciplinary research networks. Of utmost importance is to educate our colleagues in methods of retrieval, organization and filtering of information that allow them to keep abreast of the latest developments in their areas of interest.

## 6. Viewpoint 5 – Biomedical Informatics: Multiple Disciplines, Multiple Visions

Medical informatics, bioinformatics, health informatics, clinical informatics, imaging informatics, e-health, public health informatics, dental informatics, nursing informatics, genomic informatics, clinical bioinformatics, molecular informatics, chemo-informatics, pharma-informatics, computational biology, neuroinformatics, biomedical computing (and more!). The number of biomedical informatics-related disciplines and areas has grown considerably over the past four decades – and even more so if one counts changes and nuanced overlaps in the names of the different subfields. The inclusion of the term “informatics” in the name of several of these disciplines, with its implication about the centrality of methods of information processing to the subfield, can justify – at least, partially – the difficulty of providing a solid, scientific definition for the entire, inclusive discipline most frequently referred to as biomedical informatics (BMI). While from a mathemat-

ical perspective, the term “information” was precisely defined by Shannon in his mathematical theory of communication [31, 32], its actual use, particularly in BMI, has little to do with Shannon’s theory of signals and their transmission over communication channels of varying capacities. Social, cognitive, communication, scientific, historical, psychological, political, economic and other issues are usually included within the broader colloquial sense of “information” that is most frequently meant by authors in BMI. This is also true for medicine as a whole, where rarely is information meant in Shannon’s information-theoretical sense.

With Kulikowski, we have argued elsewhere [33] that eschewing scientific theories and principles in biomedical informatics might be seen, from the perspective of the philosophy of science, as a sign of possible scientific instability in a discipline. In this case we might say that biomedical informatics is still immature scientifically, since its theories about the content (as opposed to the syntactical uncertainty of transmission) of information have as yet failed to crystallize in scientifically testable ways. This judgment of immaturity will only be justifiable in retrospect, once broader, testable theories about the semantics and pragmatics of information have been developed, and does not imply that technological or engineering success, funding, and relevance, to future science should be ignored, either at the academic or industrial levels. However, the patent need for deeper scientific foundations, which has been boosted by the success of the Human Genome Project (HGP) at the end of the 1990s, has led medical informatics professionals towards genomics and bioinformatics in search of new research opportunities. This has led to proposals for combining (merging or linking) medical informatics and bioinformatics into BMI [34–37]. Now, only a few years since this combined field definition, while genomic and personalized medicine are still under development, nanomedicine appears as a new promising frontier for BMI [38, 39]. More than 4,000 papers are already indexed with the term “nanomedicine” in MEDLINE at the time of writing. In this context, a new area that deals with the application of

informatics methods and tools to nanomedicine has been already called “nanoinformatics”; as a shorter term for “nanomedical informatics”. This can be defined as an emerging research field that utilizes informatics techniques to collect, process, store and retrieve data, information and knowledge on nanoparticles, nanomaterials and nanodevices and their potential applications in health care [26, 40–42]. The work of our BMI group at the Universidad Politecnica de Madrid in nanoinformatics includes the formulation of an agenda for the field, with research on relevant methodological approaches such as text mining, ontologies of forms and shapes based on classical mathematical assumptions, image processing, nanotoxicology, or the linking of nanoinformation to electronic health records and other proposals [42, 43]. Similarly, applications of nanoinformatics include, for example, modeling and simulation, data integration, semantic annotation and retrieval, domain ontologies, terminologies and standards, data and text mining for nanomedical research, and others [42, 43]. In the ACTION Grid White Paper a panel of experts, including BMI professionals and nanotechnologists, already proposed an agenda in the field, including various significant topics where BMI could influence nanoinformatics [44].

Thus, nanoinformatics appears as a topic where BMI can extend the scale in the spectrum of its present activities. The health, economic, industrial, academic, ethical or political implications of nanomedicine and nanotechnology are enormous, promising to create breakthroughs in various health-related areas. Its very different potential for therapeutic action promises a scope of application that may lead to a whole new BMI agenda in the future. However, “nanoinformatics” also increases the over-proliferation of names, disciplines and subfields already mentioned above. My perspective here is that the challenges and needs of nanomedicine are so important that informatics proposals and professionals dedicated to the area will necessarily grow up – whether inside or outside BMI. The latter can accelerate developments in nanomedicine, similarly as happened with bioinformatics and the HGP. In addition, nanoinformatics is al-

ready providing new insights for BMI, which can lead to raising new questions and problems for future research. In this regard, I point out below some examples of early insights, which might be expanded in the future:

1. Knowledge and method reuse and extensions. As mentioned above, many topics already included in nanoinformatics are similar to those already developed for BMI [43–45]. However, the underlying disciplines are different – medicine and biology for BMI, chemistry and physics for nanoinformatics – and so, specific adaptation is required. Thus, new translational research topics can be envisioned and can lead to new discoveries for biomedical research and health care.
2. Lack of unifying principles or theories. Various proposals have been made aiming to provide solid scientific foundations for BMI, which could help open up new research agendas and articulate the discipline. Crick’s central dogma was an early foundational support for bioinformatics [46] – now found to be insufficient for the postgenomic era, suggesting that for this part of BMI new theoretical approaches and foundations are necessary. Anyway, the broad and highly heterogeneous scope of BMI – even enlarged to include nanoinformatics – and of the term “information” as it is now considered, makes it difficult to imagine such central theories – or a “fundamental theorem”, such as the one proposed in [47] – having more than a heuristic, and transient impact. It certainly does not provide a central scientific foundation for the broad spectrum of BMI. For instance, “information” at the nano level raises very different problems from the physical and chemical perspectives, for which new types of “information processing theories” will be necessary. Such new insights may prove useful for BMI as a whole.
3. Recent approaches in biomedical ontologies – e.g., for developing upper ontologies – [48, 49] aim to facilitate consensus and interoperability of ontologies and information sources. We have analyzed some of their applications in nanoinformatics in a recent MIM paper

[50], which was commented on pro-and-con by various authors [51], indicating that the issues raised demand thoughtful debate. The introduction of information from nanoparticles is an example of a serious challenge to current biomedical ontologies, since the kind of current qualitatively-focused ontologies that are widely adopted in biomedicine cannot fully address, for instance, fundamental visual and graphical information from nanoparticles – or proteins, molecules, viruses, etc. – as needed in many areas of nanomedicine [50].

4. Openness in data and information resources is quite different across the width of the spectrum of BMI. While many data and resources are already open in bioinformatics, questions of safety and security in clinical data have impeded the practical realization of a vision for such open software in MI. Meanwhile, nanoinformatics will introduce new topics about proprietary issues of nanoparticles, nanotoxicology and it can serve as a testing field for many open informatics resources – after adaptation to its special characteristics.

Finally, to conclude this note, we have to remember the tremendous impact that information resources and tools have already had on all aspects of biomedicine. Besides the impact that has transformed healthcare and biomedical research in many places – and it is most promising for the future of developing countries – BMI professionals have tried to expand the spectrum of the discipline, towards new challenging fields, as with genomics fifteen years ago and with nanomedicine now. However, we have to recall that many successful disciplines, like physics, required a long time to reach a mature status. By trying to introduce shortcuts – proposing new approaches or theories insufficiently supported by scientific evidence –, the discipline could face serious challenges to its inner coherence and its recognition from other scientific and technological disciplines. In this regard, no “deus ex machina” can provide magical solutions to solve the many issues and challenges that BMI seeks to address, located as it is, at the confluence of multiple disci-

plines and visions. Finally, the different visions provided by the participation of this multiplicity of disciplines – and people – results in a highly heterogeneous and challenging set of subfields, like with nanomedicine, which must, nevertheless, be subject to empirical and scientific testing so as to develop reliable principles and knowledge that will help extend the field in new directions, where the theories and models of information as applied to biomedical problems can be applied.

## 7. Viewpoint 6 – Biomedical Informatics: Confluence or Converging of Disciplines

A commonly used definition of biomedical informatics is “the field that is concerned with the cognitive, information processing, and communication tasks of medical practice, education, and research including the information science and the technology that support these tasks” [52]. This definition stretches the conventional boundaries of informatics and places computing and technology in a more supportive role. We have now recognized that biomedical informatics is more than the thin intersection of computing and medical practice. An emphasis on communication and collaboration has also been suggested by Hasman and Safran [53]. This captures a critical shift in the nature of the informatics paradigm. It suggests a place of prominence for the human dimension as reflected in the social and cognitive sciences. Cognitive science’s relationship to biomedical informatics began through the medical artificial intelligence and medical decision-making communities [54]. However, we have recently seen a prominent inclusion of methods and theories from the cognitive science discipline in biomedical informatics. I suggest that these disciplines are not confluent, but are connected by bridges, some of which are more developed than others. These bridges provide flexibility. Maintaining rigid disciplinary structures does not allow sufficient adaptability to capitalize on important trends or to leverage the influences these trends have on

biomedical informatics. For example, social networking has profoundly influenced behaviour change and transformed the way people work. Furthermore, as text-based chat, web forums, Facebook and personal messages are the predominant modes of communication in online social networks, recent advances in automated text analysis allow for large-scale analysis of the content of communication among members of a social network. Here we see the interplay of methods and a community of practice for information exchange.

The integration of social and cognitive sciences in the field of biomedical informatics, which has long embraced computer and information sciences, presents some interesting challenges. These disciplines can inform and shape the field to generate a more comprehensive and broader perspective, which requires the development of shared objectives, methods, and vocabulary. These shared viewpoints are still evolving and help to define the research agenda for the future.

The evolution of any discipline mirrors natural and cultural evolution. Any community of learning and practice made up of people from diverse areas – such as computer science, epidemiology, information science, and biomedicine, as well as educational research, sociology, anthropology, and psychology – needs to find a means of effective communication of meaning so as to share among the participants. Each of these disciplines has evolved its own language of communication, and there is always a struggle to find common ground. Most of this communication occurs at the bridges mentioned earlier. The emerging attempt to communicate is usually a *mélange* of terms and structures from various languages of origin. Such efforts serve as the means for minimal or functional communication. An example of such emergence would be an attempt by medical informaticians to identify conceptual units and their organizational structures. The foundational disciplines use a range of constructs for these notions, including “terminology” (from information science), “vocabulary” (from medicine), and “ontology” (from computer science and philosophy) [55, 56].

We have recently seen these disciplines coming together through the development

of a more common “language”. This has had a major impact on the field in research as well as in education. However, these are still not fully integrated languages in a sense that the roots of all languages in other disciplines are clearly apparent. One area of biomedical informatics research involves defining standards for exchanging information among systems. The diverse informatics community has settled on the term “message” for the unit for exchange. This term is now widely understood, and it has a distinct meaning, different from its meaning in medicine (which is more concerned with content than structure) or in computer science (where it has a predominant meaning related to object-oriented programming). Similarly, in cognitive science, (human) information processing has taken on a different meaning from its more conventional usage in computer science.

Given that many of us are not “native” speakers of biomedical informatics, but have liberally drawn on our native disciplinary tongues, it is a challenge to develop a mature discipline in which everyone speaks the same language that affords a range of grounding in communication strategies to coordinate shared meanings [57]. While biomedical informatics is developing a substantial shared terminology, there are still considerable idiosyncrasies that hamper communication. Controlled medical vocabularies are an interesting case in point, because there are several emerging standards, each with different assumptions and subtle differences in meanings that can create boundaries. Analysis of social network structures and domain complexity tell us that most problems arise at the boundary where two fields are trying to merge to create a new communication structure. This method can provide us with an opportunity to investigate in greater detail what happens when two boundaries collide.

In the current state of informatics, methods, theories, and concepts are drawn mostly from computer, information, and cognitive sciences. Cognitive science has been added recently as it contributes to the basic science dimension of biomedical informatics while it informs the practical aspects having to do with design and implementation.

Despite the potential of health information technologies, their implementation and integration into medical practice have often proved to be more difficult than we anticipated [58, 59]. Much research has focussed on a range of technical issues in the implementation of these systems, including computer communication and networking, physical input devices and the development of software standards for controlled medical vocabularies [60]. However, the most recent addition of cognitive and social science research perspectives has promoted the investigation of cognitive and social dimensions of clinicians’ encounters with computer-based technologies [61].

In medical practice, human-computer interaction is a science of design that seeks to understand and support human beings interacting with technology [61]. However, these are grounded in the socio-technical systems involving the culture and the social norms of the group. Training is an essential (and often overlooked) ingredient in promoting the effective use of health information technology [62]. One future challenge we will face is to adapt to the constantly shifting balance between recognizing and promoting these technologic changes and understanding the social consequences. The other challenge will be to train professionals to think and to make high level decisions, while lower level decisions are taken over by technological support [62].

As multiple streams of other disciplines move toward the field of biomedical informatics, we would like to see the boundaries dissolve and start to be a confluent, but there are challenging social, communication, and technical issues that tend to make such convergence a part of the research agenda.

## 8. Viewpoint 7 – Evaluation of Biomedical Informatics as a Confluent Discipline

Biomedical Informatics is a multi-disciplinary discipline at the intersection of computer science, information science, medicine and nursing [15, 63]. Methods and tools developed within health in-

formatics have shown to improve quality and efficiency of health care. However, insufficiently designed and ill-functioning Health Information Technology (HIT) may not only lead to disruptions in clinical processes, but even to patient harm [64].

Evaluation has been proposed as a measure to counteract these negative aspects [65]. Evaluation is considered an ethical imperative. One has to thoroughly assess the impact that HIT has on the organization, the sociotechnical system and the care the patient receives [66].

Not only does the scientific community stress the need for evaluation: The European Commission has adopted a revision of the Medical Device Directive (MDD). In this directive, software used for diagnosis, prevention, monitoring, treatment or alleviation of disease, injury of handicap is also considered a medical device. Part of this MDD is a clear description of the essential requirements that a medical device has to meet (among others safe for patient, user and third party) and the means to demonstrate how to prove compliance with these requirements (a process called clinical assessment) [67].

This increasing awareness of the need for well-designed systems and their systematic evaluation is termed Evidence-Based Health Informatics [68–70]. The trend towards Evidence-Based Health Informatics is reflected in several recent developments: We can, for example, observe a rising number of evaluation studies in health informatics [71], an increasing discussion on negative outcomes of information technology in health care (for example [64], with follow-up discussions for example by [72] or [73]).

Bringing Evidence-Based Health Informatics into practice is challenging. Some effects of applications can and have been assessed using randomized clinical trials (RCTs). Such studies borrow their methodology from epidemiology and biostatistics. But not all effects can be assessed using this golden standard in health research and health technology assessment. Implementation of HIT in a health organization can also be seen as an intervention in the organization, leading to changes in work practice and interpersonal relations and to shifts in responsibility. Similar as-

pects of implementation and adoption of IT have been observed in other industries, where researchers with a background in management science, sociology and psychology have studied these effects. There is an increasing interest in why certain applications are easily adopted in clinical settings and other applications fail to be adopted. Various studies in biomedical informatics have assessed the value of models from information and management science on the adoption of technology (e.g. TAM – Technology Adoption Model or UTAUT – Unified Theory of Use and Adoption of Technology [74, 75]). There is also an increasing interest in the safety of the HIT applications for the users. Koppel et al. have demonstrated the risks of using HIT with less than optimal interface design [76]. Developing and evaluating HIT user interfaces is a discipline in itself since it requires the expertise of cognitive psychologists and usability experts in combination with a proper understanding of the clinical work processes [77]. IMIA and EFMI have working groups specifically addressing the Human Factor Engineering aspects that work together with the evaluation working groups.

The described multi-disciplinarity of evaluation as part of biomedical informatics reflects the fact that biomedical informatics is in itself a multi-disciplinary science. Each of the listed disciplines has its culture and terminology, its own programs and methods, and its own history. It is necessary to learn from these disciplines to adopt, adapt and integrate their paradigms in those of biomedical informatics. Evidence-Based Health Informatics needs to develop inter-, cross- and multi-disciplinary approaches that help to really understand what happens when informatics interventions are introduced and are penetrating the complex healthcare setting.

Evaluators need to know the limits of their knowledge. Rather than develop a method for a problem, they should search other disciplines for solutions and invite scholars from those domains to make sure that they learn what the limitations and assumptions are for the application of those methods. It would be helpful when a repository of evaluation approaches is developed, together with the evidence base of

their value for studies in health informatics. That will provide a first guidance of methods that are suitable for particular study questions, but cannot and should not be a replacement for the involvement of experts from other disciplines in our evaluation studies.

As early as 1996, an issue of *Methods of Information in Medicine* was devoted to the question: “Is biomedical informatics an art or a science?” [78]. At least for the area of evaluation research, we would follow Nagm et al. [79] who argue that the evaluation of information systems “is not only a science but is also an art form which involves creativity, improvisation, imagination and community building”. This combination of the confluence of various scientific disciplines (based on objectivity, reproducibility and well-defined methods) and of art (based on the personalities of the researchers and the participants and the context, culture, and complexity of the health care organizations) is a big challenge for health informatics, but also a great opportunity to bring health informatics further as a mature discipline.

## 9. Viewpoint 8 – Biomedical Informatics: Towards Information Bridges for the Health Information Society

### 9.1 Introduction

Biomedical informatics has an interdisciplinary nature, because it is necessary to apply and advance informatics methods in medicine and to understand systems and processes in health care. Biomedical Informatics is evolving fast, since several disciplines that influence medicine and health care are evolving as well as medicine itself. The result is an increasing amount of data, information and knowledge that needs to be stored, analyzed and presented in an adequate, flexible and context sensitive manner to enable competent decisions of various stakeholders:

**Physicians:** Telemedicine applications and inter-institutional data exchange provide additional information for physicians (E-Health [80, 81]). The aim is to enable

high quality care as well as to avoid double data entry and double examinations (e.g. electronic medical record systems in developing countries [82]), electronic health records (EHR, e.g. [83]), interinstitutional data exchange [84, 85]), use of personal digital assistants (PDAs) [86]).

**Patients:** Personal electronic health records are broadly discussed, but not yet widespread. In contrast to that, the Internet is used by a broad variety of people to gain knowledge about diseases. Due to the expected demographic change in developed countries, ambient technology for older and chronically ill people is under investigation to enable a secure life at home ([87, 88]).

**Research:** Advances in genomics and proteomics have led to research results of biomedicine, which are clinically relevant. The better understanding of causes of diseases enables new and targeted therapies. Additionally, organization and visualization of data can support epidemiologists and public health researchers in generating hypotheses ([89]).

All these developments lead to new and partly huge amounts of data that is potentially available for decisions in medicine. New opportunities arise if data are provided for additional purposes. In the following viewpoint, the necessary information bridges are described. Confluent disciplines are necessary to build these bridges.

### 9.2 Bridging Patients’ Daily Life and Health Care

Ambient assisted living (AAL) is expected to save costs to cope with the demographic change. Nevertheless, technical assistance is not sufficient. Patients have to be empowered and participate more in the care process. Healthy lifestyle and treatment compliance has to become a basic need of daily life [90], comparable to nutrition and sleep. For doing so, patients need information and feedback about their health status.

Ambient technologies offer new data sources for decisions in health care. Data from technical devices can provide the physician with continuous information about vital signs, patient behavior and status. In addition, physicians are con-

fronted with better-informed patients, who might have their own ideas about potential therapies.

The challenges for biomedical informatics in this field are manifold. We must elaborate how biomedical informatics can help to achieve patient empowerment. Information systems are needed that are able to tailor information and knowledge according to patients' diagnoses, level of knowledge, behavior, and personal interests. Personalized interfaces and context-orientated views are needed. Physicians have to decide which information can be accessed and manipulated by patients. Clinicians and researchers have to provide high quality medical knowledge that can be understood by patients with different competencies.

The amount of new data for decisions in health care is enormous, when a patient is monitored continuously, records the data in his personal health record, and when several institutions participate in the care process. Intelligent algorithms and presentation techniques are necessary to avoid information overload and enable efficient information retrieval. Algorithms are necessary that are able to interpret sensor data, infer the patient state, learn about typical behaviors and attitudes and detect critical deviations.

### 9.3 Bridging Research and Care

New opportunities arise for physicians by receiving electronic information not only from patients and other health care institutions. Data from biomedical and genetic analyses are available for decisions on further diagnosis and treatments. The better understanding of molecular processes and genome alteration is expected to lead to more individual therapies (personalized medicine). Translational medicine evolves as a result of the endeavor to bring scientific results 'from bench to bedside' and influences also clinical research. We currently have just started to support these processes by adequate information management and ICT.

Despite all these advancements we have to be aware that it is still difficult to use data recorded in the context of care for clinical

trials without reentering them as has been demanded already in 1964 [91]. More than 45 years later, this is still a challenge and an increasingly discussed topic ([92]).

### 9.4 Bridging Patients and Research

Data in clinical trials are not only enhanced by data from biomedical and genetic analyses but also from data of patients' daily life (AAL), and patient reported data. Many of the above mentioned challenges also apply in this context. Clinical trials have high standards for data quality. New approaches are needed to face the challenge of different data quality from sensor data, patient reported data and physician reported data.

Patient consent is a major prerequisite to be able to use patient data for medical research. When no consent is given explicitly, the possibilities to use anonymous data from different sources should be elaborated. The enormous amount of data from new data sources can lead to more information about rare disease and can help to reach necessary sample sizes.

### 9.5 Confluence of Disciplines

Data available for decisions are comprehensive and multifaceted. Several disciplines are involved in enhancing decisions of patients, physicians, and medical research and in building information bridges: Biosciences (molecular biology, systems biology, biostatistics), informatics (medical informatics, bioinformatics, business informatics), engineering (medical engineering, telecommunication, ambient assisted living), social sciences (patient behavior, requirement analysis, technology acceptance), mathematics (medical models, [bio]statistics, medical biometry).

It is important that researchers of all these disciplines exchange experiences and learn about the mutual requirements. To continuously advance (bio)medicine the strengths of each discipline should be accumulated. As an example, due to the enormous scope of results of microarray experiments, informatics methods are necessary

to store and compare the data and new biostatistical methods are necessary to identify relevant results (e.g., to predict the relative importance of each gene for sample classification).

### 9.6 Conclusions

Information in health care is a treasure for high quality care. Bridges are an important means to get over limitations and to recover the treasure. A lot of opportunities arise, when information is exchanged among the decision makers in health care. A major prerequisite is the interoperability of information systems. Syntactic interoperability is increasingly established in eHealth solutions. More difficult is semantic interoperability [94], which is an important prerequisite for automatic processing of data and for reusing care data for medical research [95].

To use information as treasure, basic steps still have to be taken. Structured data entry has to be established much more consequently as a prerequisite for data integration and automated analyses. Physicians have to become aware of the usefulness and the ease of use of highly structured data (cf. TAM [96]).

To really face the demographic change we need to maximize our endeavors beyond technology development. Patient empowerment and technology acceptance are the crucial step towards the health information society. Interdisciplinary cooperation (e.g., with the social sciences) is needed, to prepare the society for using information systems as a means to stronger participate in the care process.

## 10. Viewpoint 9 – Biomedical Informatics (BMI) and Biomedical Engineering (BME): Synergy or Competition?

Biomedical Engineering (BME) and Biomedical Informatics (BMI): two obvious different approaches to solve problems in biomedicine and health care? Do they have a shared potential? What are their specific

capabilities and what is their role and impact on the challenging prospective tasks of research in medicine and health care?

At the time of early computer science 50 years ago, BME had a rich and highly fruitful tradition of assisting and complementing medical diagnoses and therapy [97]. It was a matter of fact that the technical developments for devices and methodologies in medicine dependent on calculating and number crunching or intelligent functions and sophisticated algorithms, logical concepts and data management were supported by engineering sciences as well as by computer science or informatics [98]. However, both fields also developed their own characteristics, applications and methodologies.

### 10.1 Recent Developments in Biomedical Engineering and Biomedical Informatics

Progress in all fields of technology, new materials with specific biocompatible properties, energy efficient power supplies, nanoparticles, micro-system technology, fluidics and especially the high degree of inte-

gration and miniaturization enable a variety of fascinating new techniques, devices, methods and approaches in biology and medicine.

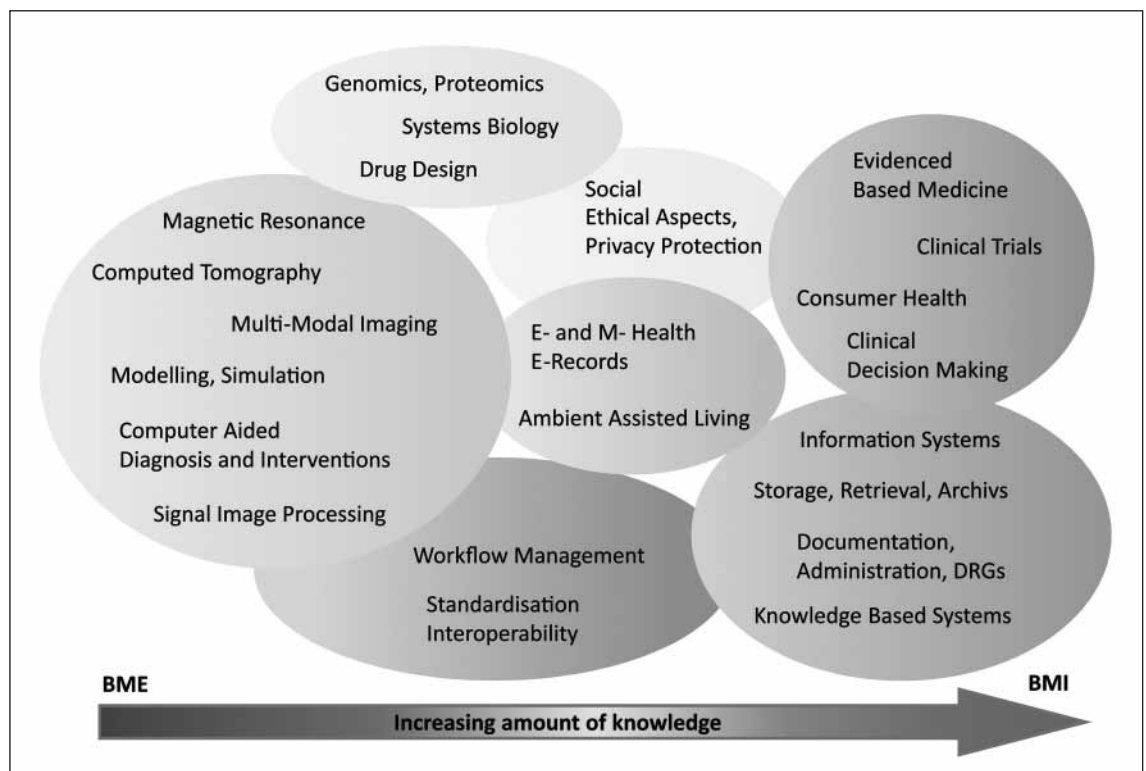
The huge variety of rapidly developing imaging technologies, such as Computed Tomography (CT) and Magnetic Resonance Imaging (MRI), complement each other perfectly and allow for manifold support of diagnoses as well as for planning and performing surgical interventions. Together with robotic and navigation technologies, they enable a substantial progress with respect to accuracy and surgical outcome [99]. Functional imaging modalities, such as fMRI, PET, SPECT as well as molecular imaging with different kinds of tracers and particles, open doors for a better understanding of physiology and efficient treatment of cancer patients [100, 101]. Another field with increasing relevance is emerging with active implants, artificial organs, neuro-prosthetics and man-machine interfaces [102, 103].

The broad spectrum of devices, instruments and products, techniques and approaches is, on the one hand, driven by the challenging problems that modern societies are facing, but on the other hand also

by new technical opportunities and their potential.

Looking at Biomedical Informatics, we recognize a partly close relationship to Biomedical Engineering (► Fig. 2). However, there are many other expanding areas and challenges which are typical for the broad field of health care, medicine and Biomedical Informatics with all its various facets.

Storing, archiving, intelligent retrieval and data mining are essential for running all kinds of information systems, data repositories and warehouses, even PACS and molecular databases. Also, documentation of patient records and administration are still integral tasks within clinical routine. Newly, modern grid technology facilitates efficient data processing of ambitious scientific projects run by connected partners. Likewise, integrated frameworks and platforms for managing different kinds of patient data from multi-centered clinical trials are essential to derive metadata and knowledge for new therapy strategies. To support clinical decision making for therapy and diagnosis, expert- and knowledge based systems are being developed and need further improvements [104]. A recent and rapidly growing field with high impact



**Fig. 2** Application areas for biomedical engineering (BME) and biomedical informatics (BMI)

on individualized medicine is bioinformatics and its application to medicine on a cellular and molecular level [105]. Research in genomics and proteomics, supported by specialized databases and intelligent retrieval methods, provides new opportunities for drug design, treatment and prevention and elucidates the relation between genotype and phenotype [106, 107].

Because of the increasing complexity of interconnections between various partners and different types of systems, standardization and interoperability should be maintained and improved. An important basic issue for all kinds of applications is privacy protection and data security. These concepts have to be considered particularly in the light of recent mobile health care and web applications.

## 10.2 Grand Challenges in Biomedicine

What are the grand challenges in biomedicine and healthcare? How can BMI and BME contribute to solving these problems in future? Globalization with all its various consequences, the demographic development of societies, unbalanced availability of natural resources, such as water, food, and finances, as well as a change of lifestyle etc. have a strong impact on health, prevention and care. The WHO calls for greater benefits of health informatics on basic levels, particularly for developing countries. However, this requires new technologies like e- and m-health and new diagnostic facilities. The technical and logistic prerequisites should be established in order to provide ubiquitous and universal access to medical advice and information. Broadband technology, open access- and service oriented software as well as call- and emergency centers have to be established.

For industrial countries, consumer health aspects regarding thoroughly networked and empowered patients should be kept in mind while adapting health care systems for future needs. Personalized medicine requires much more research and development on a biomolecular level as well as engineering efforts to design and implement necessary sophisticated instruments. Nano-medicine and regenerative

medicine including stem cell applications are challenging tasks for the near future [108]. Furthermore, assisting technologies like smart homes with different services, monitoring and alarm facilities offer opportunities for a rapidly ageing population with increasing co morbidity.

Also strategies for prevention of illness by providing information, education and detection of early symptoms have to be fostered to lower the rate of chronic diseases. Not only for third world countries, mobile, simple and cheap test procedures and devices are necessary, such as emerging BioMEMS and Labs-on-a-chip.

## 10.3 Conclusion

Coming back to our initial question of whether BME and BMI are competitive partners the answer might be yes, as both fields compete for the best solution with the background of their individual competence and experience. However, this struggle for optimal solutions does not hamper the development, but on the contrary enhances the process of problem solving. From that point of view, we conclude that BME and BMI are highly competent partners in the future, dependent on each other in order to achieve the synergy that is absolutely necessary for progress in health care and biomedicine for the upcoming decade [109].

This conclusion seems to be already implemented if we take a look at prospective academic programs for educating students and professionals in BME and BMI. The recent published IMIA recommendations for education [16] already regard both fields and underline their synergistic character. This is an encouraging finding for the future.

## 11. Viewpoint 10 – Can Health Informatics and Bioinformatics Be Merged into One Discipline?

Health informatics is the study of the principles behind information delivery in health care. The term information delivery

in this definition implies aspects ranging from the creation of ontologies and terminologies, via information systems development, implementation and evaluation, data capture, analysis and interpretation to communication. Health informatics has been with us for at least 50 years. Bioinformatics is a younger discipline and is about thirty years old. Bioinformatics deals with the creation and analysis of large biological datasets in order to enrich biological knowledge with the help of informatics.

The domain studied in health informatics is different from that in bioinformatics. Bioinformatics concerns biology and is about amino acids, nucleotides, genes, etc, whereas health informatics concerns medicine and healthcare and emphasizes the patient, signs and symptoms, diagnosis and therapy. Of course, there are areas of research where the two fields have to cooperate: diseases can have a genetic component and therefore there are hypotheses (e.g., the genetic causes of diseases) that have to be tested using relevant patient data. Both health informatics and bioinformatics are applied sciences and mainly focus on the methodology. The knowledge ensuing from research by these disciplines mainly concerns the domains they study or aspects of the methodologies they apply.

Although both disciplines study a different domain, there is an extensive overlap in the methodology used in health informatics and bioinformatics. Besides the fact that they sometimes are complementary as mentioned earlier, in certain research projects there is a need for contributions from both fields. In health informatics, for example, a lot of methodological knowledge exists about how to get rid of noise in signals and images that is also useful for application in the analysis of microchip data. Image analysis itself is used in both fields.

In both fields, the creation of ontologies is important. Also, text mining is a methodology that is both important in bioinformatics and in health informatics. Of course, databases are important in both disciplines. Certain problems can be studied either by health informatics groups or by biological groups [110].

In my opinion, there is hardly any reason – because of the large overlap in methodology – to consider the fields as different

disciplines. They are branches of what is now called “biomedical informatics.” The difference between the branches lies for a large part in the application domain. A similar situation exists in physics. Its basic knowledge drives the many branches that focus on electromagnetism, mechanics, thermodynamics, relativity and quantum mechanics, for example. Physicists have to specialize because it is not possible to oversee the whole of physics anymore. This is also the case in biomedical informatics. There is a difference: physics is both a fundamental and an applied science whereas biomedical informatics is an applied science that uses the theory of many disciplines. One can raise the question whether biomedical informatics has its own body of knowledge. Perhaps reusable domain ontologies and problem-solving methods are the core contributions of biomedical informatics research. According to Musen, we can understand many central activities within informatics in terms of defining, refining, applying, and evaluating domain ontologies and problem-solving methods ([111] and in this contribution). I agree with him.

The above viewpoint also has consequences for education. The field to be taught now is biomedical informatics, and in biomedical educational programs the domain knowledge of both branches will need to be presented. The basic knowledge would be presented to all students. Thereafter specialization would take place by offering various specialization tracks to the students.

### 11.1 Conclusion

In this contribution, I argue that the fields of health informatics and bioinformatics can be considered as branches of biomedical informatics. Of course, the problems bioinformaticians are confronted with are usually different from the problems health informaticians encounter because of the different domains they study. However, the methodology they use does overlap a lot. Therefore, both fields can be considered as a specialization of biomedical informatics. This situation is analogous to the situation that for example exists in physics.

## 12. Viewpoint 11 – Confluences of Education in Biomedical Informatics

There are many opportunities worldwide for obtaining education in the field of Biomedical Informatics (BMI). In a number of countries, there are extensive educational components in BMI at different levels of education and for different health care professions. Increasingly, dedicated programs exist that consist of organized, structured sets of course offerings aimed at preparing participants for specific career paths and culminating in a degree, diploma or leaving certificate.

Because a variety of educational and health care systems exist all over the world, programs, courses and course tracks in BMI may vary in different countries. In spite of this variability, basic similarities in BMI education can be identified and used as a framework for recommendations. The revised IMIA recommendations [16] should be regarded as a framework for national initiatives in BMI education, and for constituting international programs and exchange of students and teachers in this field. They also encourage and support the sharing of courseware.

There exist different perspectives for BMI education. For BMI specialists we especially can distinguish between a more informatics-based and a more health care-based approach to BMI education, with a variety of combinations in-between. It is important to recognise the need for teamwork as all biomedical informatics projects require input from more than one person each with their own unique skill set, so that the team as whole is able to address all project aspects in a cohesive and coordinated manner.

The objective of an informatics-based approach to BMI is to focus on the processing of data, information and knowledge in health care and medicine with a strong emphasis on the need for advanced knowledge and skills of BMI, of workflow, people and organisational aspects, of mathematics, as well as of theoretical, practical and technical informatics/computer science, especially semantic interoperability, ontology based software engineering and its rela-

tionship with effective and safe data, information and knowledge processing and representation.

The objective of a health care based approach to BMI is again to focus on the processing of data, information and knowledge in health care and medicine requiring, apart from knowledge in BMI, also knowledge in medicine or other health sciences to such an extent that can only be imparted within the scope of a medical or health science education. In such an approach to BMI education, clinical knowledge and skills predominate but these must be applied within the BMI context.

Both pathways, the one which is health care originated and the other which is computer science originated provide the confluence of adequate and quality based education in BMI and both concur with the accreditation and certification standards that may be applied.

## 13. Conclusions

It is clear from the different viewpoints expressed in this contribution that BMI is considered to be a broad field that is still expanding. BMI has both a scientific aspect and a constructive aspect (designing and developing information systems). The fact that researchers with different backgrounds are involved in research in BMI makes its multi-disciplinary character obvious. However, is it also interdisciplinary? If so, BMI must have more to say than the sum of its supporting disciplines. According to Musen the essence of BMI, the modelling of biomedical content, distinguishes it from related disciplines. Therefore BMI can be considered interdisciplinary. In their presentations, the authors often refer to biomedical informatics techniques that can be used to make medicine safer and better. These systems need to be evaluated. Also for evaluation purposes approaches coming from various disciplines are needed. Therefore, the evaluation of the constructive aspect of BMI is multidisciplinary.

Some of the contributors to this article not only look at BMI but also at other scientific disciplines. The languages of scientific disciplines can be very different

and since the research findings of these disciplines are stored in different bibliographic databases it is therefore difficult to connect findings in these databases to obtain new knowledge. It is probably not possible to have confluences between these disciplines but bridges between them will make new knowledge easier to obtain. Education has a role to play to make students aware of the broad field of biomedical informatics but also to stimulate them to look further than the boundaries of their own discipline.

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