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Expert Systems with Applications 30 (2006) 11–23

Expert Systems with Applications

www.elsevier.com/locate/eswa

Networkcentric healthcare and bioinformatics: Unified operations within three domains of knowledge

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Abstract

Bioinformatics is a rapidly developing field of quantitative biomedical research with the potential to transform the three principle domains within healthcare operations of research, clinical practice and administration. Presently, a significant part of bioinformatics research concentrates on genomics and proteomics. Despite growing clinical enthusiasm for the discoveries and creation of new information and knowledge that such research brings, current results are still outside the daily clinical reality. As a measure to close the gap and integrate bioinformatics into the rest of the healthcare domains, the authors propose a networkcentric approach. Based on operations within the unified space created by the overlap of three domains of knowledge, networkcentric healthcare operations support free information flow among all constituents (actors) within the healthcare space, rapid generation and exchange of pertinent knowledge, as well as enhanced awareness of the significance and practical implementation of new discoveries within specialized fields of biomedicine (e.g. bioinformatics). Healthcare networkcentricity will also facilitate conversion of information into readily accessible knowledge, accelerate translation of that knowledge into clinical practice, and reduce the stress of information overload. Changes in the use of Information/Computer/Communication Technologies (IC^2T) and enhanced efficiency of Decision/Executive Support Systems (DSS/ESS) are pivotal to the success of the networkcentric approach as discussed in the paper.

Keywords: Bioinformatics; Networkcentric; Platformcentric; Boyd; OODA Loop; Healthcare; ICT; Knowledge; Medical informatics; Healthcare informatics; Healthcare management; Healthcare domains; Medical research; Bio-medical research; Clinical practice; Information management; Data; Specialty integration; Information overload; Medical operations

1. Bioinformatics and healthcare

According to the definition of NIH, bioinformatics is 'the analysis of biological information using computers and statistical techniques; the science of developing and utilizing computer databases and algorithms to accelerate and enhance biological research' (www.niehs.nihgov/glossary.htm). The importance of the new field is underscored by the fact that scientists whose native languages do not have a proper equivalent of the word 'bioinformatics' not only engage in a vigorous research within the field, but also provide a more specific definition of the term, describing bioinformatics as science that 'aims to understand living thing as a whole, where both genome information and mathematical model play complimentary roles' (Ashida, 2002). What is bioinformatics, then? Can we restrict this new and potentially critical branch of biomedicine to the narrow limits of genomics, proteomics, advanced statistics, and computational mathematics? (Claverie, 2000) A number of recent papers indicate the willingness of embracing the new field by the ancient, established and, to a degree, conservative giant—medicine (Bostock & Harding, 1982; Graf, 2000; Hohlfeld &and Brand, 2000; Hurko, 1997).

Medicine is not a stranger to the use of quantitative methods. Fick's 'Medical Physics' (1856) is probably among the first monographs devoted to the application of physics as a tool to explain medical phenomena (Fick, 1856). However, the true explosion of quantitative biomedicine took place after the Second World War, when new techniques, particularly in physiology, allowed sufficient precision and constancy for gathering data that were suitable for quantitative analysis (e.g. Refs. (Hodgkin, Huxley & Katz, 1952; Kennedy & Sokoloff, 1957; Kruhoffer, 1954)). Even in anatomy and pathology, the disciplines seemingly impervious to quantitation, the introduction of statistical methods combined with improved microscopy/imaging techniques provided many new insights

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doi:10.1016/j.eswa.2005.09.069

on normal and diseased tissues (Ekstrom von Lubitz, 1982; Kistler, Caldwell & Weibel, 1966; Weibel & Gomez, 1962). It is, however, the advent of advanced computing techniques and information technology (IT) and their adoption by biomedical researchers that provided foundation for the ongoing transformation whose ramifications are yet to be defined.

Presently, the main thrust of bioinformatics is still aimed at proteo-/genomics (Blueggel, Chamrad & Meyer, 2004; Kellam & Alba, 2002; Kim, 2002), although several authors predict its intensive use in general medicine (Foster & Chanock, 2000; Knaup et al., 2004; Sarachan, Simmons, Subramanian & Temkin, 2003; von Lubitz & Wickramasinghe), pathology (Becich, 2000; Candy, 2000; Muller-Tidow, Diedrichs, Thomas & Serve, 2004; Rashbass, 2000) pharmacology and drug discovery (Bjelic & Aqvist, 2004; Carroll, 2004; Gago, 2004; Harrigan, Brackett & Boros, 2005; Tsai & Hoyame, 2002; Waters & Fostel, 2004), medical education (Gamulin, 2003; Johnson, 2003; Pike & Sadler, 2004), and even a field as specialized as neurosurgery (Taylor, Mainprize & Rutka, 2003). Yet, while laboratory scientists embrace the new discipline with increasing and highly practical vigor, healthcare-wide assimilation of bioinformatics continues to remain an ill-defined intent rather than a powerful drive to make bioinformatics a realistic tool of clinical medicine (Boenning & Kalfoglu, 2001).

2. Information, knowledge, and the reality of healthcare practice

There are several reasons for the mix of enthusiasm and hesitation about incorporating bioinformatics into medical practice in its most important, clinical, sense. The present world of healthcare, and particularly the world of healthcare providers, is placed under continuously increasing and conflicting demands on resources of which time is unquestionably the most scarce (Kilmartin, Newell & Line, 2002; Parshuram, Dhanani, Kirsh & Cox, 2004; Rohme & Kjekshus, 2001). The continuous need to assimilate large amounts of new knowledge and convert it into applicable clinical skills reduces the already limited amount of time available to a healthcare provider even further. Hence, the selection criteria for the practice-essential germane knowledge that must be absorbed must be both stringent and judicious. Intellectual curiosity notwithstanding, the mastered knowledge must be of direct practical (clinical) relevance, and arguments may be presented that, in the context of a healthcare practitioner, bioinformatics provides little clinically useful knowledge. Thus, if the principal role of bioinformatics in a clinician's knowledge base is that of a medium limited to the mere expansion of professional horizons, the insistence on its incorporation may but contribute to the already highly palpable state of information overload rather than to the needed gains in germane knowledge relevant to one's practical clinical activities. On the other hand, not long ago similar dismissive arguments could be used in the case of nuclear physics which today plays a crucial role in several areas of clinical practice. Thus, is it prudent to assume the same aloof stance with respect to the new domain of science merely because its link to daily (as opposed to research) clinical practice is still imperfect?

Professional competence of healthcare providers is assessed on the basis of several criteria (Epstein & Hundert, 2002). Apart from purely clinical elements (e.g. diagnostic skills), integration of knowledge and its transformation into practical skills, information management, and the ability to learn are considered to constitute some of the essential parameters defining a professionally competent physician. However, the amount of information that an average healthcare provider is required to absorb and convert into a workable knowledge base (that must be then transformed into clinical skills) is in the period of the most unprecedented growth in the history of medicine (Loudon, 1997; Sieving, 1999; Zuger, 2000). The resulting information overload (Candy, 2000; Davis, Ciurea, Flanagan & Perrier, 2004; Ebell & Shaughnessy, 2003) combined with inadequate information management capabilities appear to be among the primary causes of important information being either missed (Tsafir & Grinberg, 1998) or misinterpreted (Landry & Sibbald, 2001). For all practical purposes, high quality information—and that includes clinically highly pertinent information and knowledge provided by bioinformatics—becomes lost (Coffey et al., 2003). A partial solution to this problem is offered by evidence-based medicine where only the elements of knowledge and practice are clinically implemented that have been subjected to stringent testing through clinical trials (Landry & Sibbald, 2001).

The practice of evidence-based medicine is largely based on consistently accurate information (Cartwright, de Sylva, Glasgow, Rivard & Whiting, 2002; Graber, Bergus & York, 1999; Larson, 1999; Lopez-Lee, 2004) that, in turn, constitutes the base of equally consistently accurate knowledge (Celermajer, 2005; Folwer, 1997; Haux, Ammenwerth, Herzogg & Knaup, 2002; Mulrow & Lohr, 2001). However, one of the principal problems facing healthcare is not only how is the information gathered [e.g. Ref. (Valdes et al., 2003)], but also how it is disseminated (Mulrow & Lohr, 2001). The issue is by no means a trivial one, since the translation quality of the available information (evidence) into practice degrades with the distance between the information generator and its recipient (Fig. 1 and Ref. (Landry & Sibbald, 2001; Malterud, 2001)). The introduction of the intermediate 'information to knowledge' conversion stage (e.g. meta-analyses, major reviews) introduces potential for even greater degradation of information quality due to the subjective inclusion/interpretation of data, inappropriate data gathering techniques, or rejection of contradictory data (Tsafir & Grinberg, 1998). Finally, while the data within one domain (e.g. bioinformatics) may be of particular relevance to those who operate in the unrelated domains of healthcare (e.g. oncology or pathology), they are presented in highly specialized literature, and expressed in a highly specialized technical format (language). Either of these is typically unfamiliar to the reader from a non-specialist field. In other words, much of the information and knowledge existing within healthcare is platformcentric: it concentrates within individual sub-domains (platforms) of a large field yet, because of its highly specialized nature, remains virtually