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Guest Editorial

Special issue on cognitive informatics methods for interactive clinical systems

1. Introduction

Cognitive Informatics (CI) is an interdisciplinary domain drawing on cognitive, computer, and information sciences, addressing issues related to "human information processing, and mechanisms and processes within the context of computing and computer applications" [1]. CI research, in general, focuses on characterizing work activities and processes related to human cognition, often specifically for the purpose of designing technological solutions for improving human activities and performance [1,2]. The origins of CI research in biomedical informatics can be traced to the studies of cognition in medicine in the early 1980s. These studies were on a variety of topical areas including diagnostic and clinical reasoning, effects of expertise on clinical performance, medical education, human-computer interaction (and usability), cognitive determinants of medical error, and clinical workflow (e.g., [3–10]).

Early CI studies in biomedical informatics aligned closely, in terms of their methodological and theoretical foundations, with their origins in psychology and cognitive science. These studies were theoretically motivated, informing the training and education of health professionals, rather than the development or evaluation of clinical systems. However, these early contributions towards understanding the process of clinical reasoning and decision making have been instrumental to the development of medical artificial intelligence [11].

Although these studies were invaluable to informatics (e.g., [5]), the evolution of CI research within the biomedical informatics domain has been slow. For example, "cognitive science" was not added as a thematic category for the annual American Medical Informatics Association (AMIA) Symposium until 1996. Even so, in later years this category has been replaced with related categories such as human-computer interaction, and usability. It is also relevant to note that, through the 1990s, studies on cognition was at the periphery of mainstream biomedical informatics research [12]. However, more recent reports have highlighted its potential reemergence over the last decade [1,13].

One of the core reasons for the recent interest is the widespread adoption of health information technology (HIT), spurred both by federal mandates and by expectations of improved efficiency and quality in patient care. Adoption of HIT in clinical settings has introduced new challenges related to its use and impact on clinician performance, including usability, alignment with clinical work practices, clinical efficiency, quality, and safety [14,15].

Recent reports, such as the one by the Institute of Medicine (IOM; now, the National Academy of Medicine) on *Health IT and Patient Safety: Building Safer Systems for Better Care*, have highlighted the importance of using cognitive and human factors approaches for empirical evaluation of technology use in clinical environments [16]. In other words, they have highlighted the relevance of a deeper, and more nuanced understanding of human cognition and its limitations during the design and implementation of HIT interventions.

With the changing dynamics of clinical practice and the integral role of HIT, the impetus to understand the role and limitations of human cognition has been magnified. There is a need to adapt the existing CI-based methods to track interactive activities effectively (such as at the human-EHR interface), and developing new methodologies for tracking afforded by the ease and effectiveness of capturing large amounts of data.

In a recent review published in the *Journal of Biomedical Informatics*, we described the historical development of CI research, primary focus areas, and methodological approaches [1]. We also characterized the opportunities for CI researchers to transform the practice of clinical medicine in the age of HIT, including the use of CI approaches for real-time tracking of HIT use, characterizing the impact of HIT on clinical activities, development of mobile tools for physician- and patient-facing applications, and design of visualization tools as cognitive aids for supporting clinicians [1,17].

As an extension from our earlier review, this special issue on *Cognitive Informatics Methods for Interactive Clinical Systems* is intended to survey the current state of CI research, with particular focus on its fundamental concepts and frameworks, methodological approaches for tracking and measuring cognition, and associated empirical research using these frameworks and methods.

2. Developing effective CI research

In order to develop an effective CI research program that results in meaningful, evidence-based insights, the following considerations must be made:

2.1. Balancing clinical-relevance and theory

Early studies of cognition in medicine addressed several key topical areas including diagnostic reasoning, effects of expertise, clinical workflow, and medical errors. All of these topical areas were investigated within the context of clinically relevant prob-

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lems. For example, how do clinicians reason and make decisions with the support of an EHR (see [18])? Although the need for clinically-relevant CI research seems straightforward, there are challenges related to institutional access, requirements of time and effort for training personnel (more on this in the future directions section), the need for technical infrastructure to collect and analyze data, as well as finding the right theoretical foundations to guide such endeavors [2]. As a result of these relatively steep requirements, establishing a program of CI research is often challenging.

Closely related to addressing clinically-relevant problems, as previously mentioned, is the need for situating it within a theoretical framework. Considering appropriate theories and frameworks for the clinically-relevant problems helps in not only guiding the research process, but also increases the chances for success in real-world situations. If one focuses excessively on theory, then clinical relevance can be compromised; in contrast, if the focus is exclusively on the clinical-relevance, the quality of the empirical investigation can be compromised. This equilibrium between clinical-relevance and theoretical balance is an important consideration for CI research.

2.2. Balancing experimental control and representativeness

CI research, like most interdisciplinary research, is faced with the conundrum of balancing experimental control and representativeness. For example, a study on interruptions can be conducted in an experimental situation with simulated tasks, where there is a high degree of experimental control, but low representativeness. In contrast, the same study conducted in a real-world setting, such as a hospital floor, will have limited experimental control, but will have a high degree of representativeness. Although both studies can generate interesting insights regarding interruptions, they highlight the inherent limitations regarding the interpretation of the results. This type of constant juggle to balance the experimental control and sample representativeness, is common in CI research.

It is interesting to note that most of the articles in this special issue have chosen to focus on representativeness, addressing important clinically-relevant problems. However, this was not, in most cases, done at the expense of the experimental control, but by carefully structuring approaches for data collection and analysis (e.g., see Brunyé et al. [19]).

2.3. Generating translational outcomes

One of the key aspects of CI research is its inherent translational nature, involving interdisciplinary collaboration between clinicians, cognitive and informatics researchers, and oftentimes, computer scientists, with a goal of improving clinical practice and care. Achieving translational outcomes from CI research requires a balance between theoretical rigor and applicability in clinical settings.

Donald Stokes describes the tension in research between fundamental scientific understanding and consideration for use (i.e., application) [20]. He developed four quadrants along these two orthogonal dimensions, and characterized the most important of them as the "Pasteur's quadrant"—having high fundamental scientific understanding and practical application and use. In other words, Pasteur's quadrant is representative of the research by Louis Pasteur, whose findings regarding the theories of fermentation have a strong theoretical foundation, and has had pragmatic applications.

This quadrant, also referred to as "use inspired research"—is what CI research should ideally produce—pragmatically oriented tools and approaches that have a strong theoretical underpinning. Creating such use inspired research requires a balancing act among clinical relevance, theory, representativeness, and experimental control.

3. Articles in this issue

The articles in this special issue fall under three major categories: *conceptual frameworks* that characterize and describe human interactions in clinical settings, *theory-oriented approaches to interaction design*, and new approaches to *measuring cognition* and cognitive activities in clinical settings. The common thread across all of the categories is that they address clinically-relevant, representative problems, for improving the design, development, and use of HIT.

The articles in the last two categories—theory-oriented approaches and measuring cognition—attempt to address the use-inspired research. Drawing on existing theory or proposing new theoretical propositions regarding human-machine interactions, they suggest clinically-relevant, often very pragmatic solutions for use in practice.

There were four conceptual framework articles: two commentaries, one proposing a new theoretical lens to investigate interactive cognitive behaviors [21], and, a second, highlighting the key cognitive-engineering methods that can be utilized for the development of informatics tools and applications [22]. A special communication by Fox describes the CREDO program, a framework for understanding human expertise and developing support for cognitive tasks such as risk assessment, decision-making, and workflow management [23]. Finally, a methodological review by Roman et al. [24] describes an under-explored area of usability—challenges of user interface navigation. Although there are significant challenges posed for usability as a result of poor navigation, there is limited research explicitly addressing such concerns. The authors present a framework for characterizing navigation—within-page and between-page—and argue for the need for further research in this important area.

The articles on theory-oriented approaches to interaction design address a number of key topics: multi-media based informed consenting [25], conversational agents for portal-based messaging [26], a mobile, persuasive asthma inhaler [27], the design of a patient summary view prototype [28], user-centered approach to the development of a drug-drug alert interface [29], and a situationally-aware visualization display for emergency care settings [30]. Two studies, Antal et al. and Morrow et al., describe a theory-oriented approach for developing consumer-facing applications. Antal et al. [25] rely on multi-media based theory to design an informed consent delivery mechanism for pediatric patients; Morrow et al. describe an interdisciplinary approach to designing effective portal messages for patient centered care. The design is informed by theories of cognition including health literacy, fuzzy trace theory, and computational approaches [26].

Grossman and colleagues utilize the principles of "human augmentics," an emerging discipline regarding the collaboration among human, machine, and the environment, to develop an asthma inhaler and a companion mobile application to support medication adherence for asthma patients. Finally, Franklin et al. [30] utilize concepts from situation awareness to develop a flexible visualization application that is aligned with the opportunistic decision-making trends that are prevalent in the emergency department (ED) of hospitals.

Most of the articles in the third category were original research that utilized computational cognitive approaches for the measurement of various aspects of clinical cognition: (a) handoff communication [31,32], (b) tracking clinical workflow, interactions, and activities [33,34], (c) a special communication on the creation of cognitive profiles of users based on their use of health information exchange (HIE) data [35], (d) reasoning and expertise in the inter-