5-15-2012

HUMAN-CENTRED DESIGN: EXISTING APPROACHES AND A FUTURE RESEARCH AGENDA

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Abstract

This paper presents an analysis of Human-Centred Design (HCD), using a metatriangulation of scientific literature. This metatriangulation comprises a systematic overview of recent HCD research, in which literature is categorised and analysed using both engineering lens and cognitive science paradigmatic lenses. The study reveals that the most popular HCD approaches do not accommodate software aimed at a broad or anonymous user-base. This shortcoming can be attributed, at least in part, to the popularity of HCD approaches focusing on highly-conscious user cognition based on conceptual models. These forms of cognition rely upon learned conventions and accumulated understanding and, as a result, design approaches focusing upon them are fundamentally limited to catering for a specific subset of the human population. We identify an emerging HCD approach, which we label "Foundational Design." This approach focuses on cognitive regularities which exist in less-conscious processing, independent of culture or individual experience, and thus possibly offers a solution to the dilemma described above. Thus a future research agenda focused on the Foundational Design approach and the emerging NeuroIS research stream is proposed and discussed.

Keywords: Foundational Design, Human-Computer Interaction, Human-Centred Design, User-Centred Design, Metatriangulation.

Acknowledgement:
This research was partially funded by Department of Business Information Systems, and the Business and Law Conference Travel Support Scheme, University College Cork.

1 Introduction

The field of software interaction design is dominated by a set of approaches grouped together under the title of Human-Centred Design (HCD). These approaches share the common ideal of designing software around the characteristics of users, rather than expecting users to adapt to specific software conventions (Norman and Draper, 1986). Yet despite its popularity, several issues have emerged which threaten the future of human-centred approaches. Firstly, little consensus is evident regarding the exact definition and constitution of HCD (Hoffman et al., 2002; Vrendenberg et al., 2002). Karat and Karat (2003) compare it to 'family values,' i.e. some vague notion that everyone seems to approve of but for which no agreed upon definition exists, and note that the actual quantifiable benefits of applying HCD are not always obvious to practitioners. The second and more fundamental criticism of HCD concerns its inability to facilitate truly inclusive designs. Norman (2005; c.f. Kaptelinen and Nardi, 2006) went so far as to suggest that it had come time for designers to abandon the dominant HCD approach, arguing that human-centrism forced designers to design around the characteristics of a small number of users, furthering the creation of 'good' but not 'great' software designs.

In light of such criticisms, this paper presents a holistic analysis of HCD approaches in order to both clarify the HCD concept and to identify opportunities to advance the HCD agenda. A metatriangulation analysis of the HCD literature was performed, using both engineering and cognitive science paradigmatic lenses. This analysis reveals several trends, but most importantly identifies an emerging HCD approach focusing upon less-conscious cognition. The remainder of the paper is structured as follows. First, we present an overview of the metatriangulation method employed in the study. Next, we present the groundwork phase of the study, which defines and bounds the phenomena of interest, articulates the paradigmatic lenses used, and describes the metatheoretical sample collected for subsequent analysis. Following this, the data analysis is presented using paradigmatic accounts for the three types of HCD approach identified *a priori*, as well as for the fourth approach which emerged from the analysis. Next, the multiparadigm perspective and central metaconjecture resulting from the analysis is presented. The paper concludes by proposing a future research agenda based on the central metaconjecture that an increased number of studies focusing upon less-conscious cognitive processes, such as those described in contemporary cognitive neuroscience literature, is needed to allow HCD to overcome its significant existing limitations.

2 Overview of Method

Metatriangulation is a technique that allows research arising from heterogeneous research paradigms to be compiled into one data set and analysed holistically (Lewis and Grimes, 1999). In concrete terms, metatriangulation allows for multiparadigm literature reviews, based upon the combination of *paradigm bracketing*, where the awareness of various assumptions is attained, and *paradigm bridging*, where 'transition zones' can be identified (Schultz and Hatch, 1996; Jasperson et al., 2002). In this way, meaningful breakthroughs are facilitated by forcing researchers to become aware of, and to re-evaluate, their fundamental assumptions, in order to accommodate new types of understanding (ibid). Lewis and Grimes (1999) presented a framework for conducting multiparadigm metatriangulation reviews, which was further refined by Jasperson et al. (2002). This framework involves three high-level stages, namely performing groundwork, analysing data, and building theory.

The *groundwork* for metatriangulation requires that the phenomena of interest be defined, that paradigmatic lenses are identified and focused, and that a metatheoretical sample be collected (Lewis and Grimes, 1999; Jasperson et al., 2002). In this study, the origins and central characteristics of HCD needed to be clarified, as it is evident that the terms 'human-centred' or 'user-centred' were applied to a diverse body of literature. Following this, two paradigmatic lenses were constructed. These were the engineering lens, which divided studies into one of three broad categories of approach (although an additional type emerged), and the cognitive science lens that was used to categorize studies based on cognitive focus. Lastly, the metatheoretical sample was gathered through an exhaustive search of key research outlets for HCD research.

In the *data analysis* phase, the engineering and cognitive science lenses were applied to the data, which in this instance was the set of HCD literature that fit the selection criteria. This literature was initially categorised according to the engineering lens and an account was written - using both lenses - of each of the three categories of design approach known *a priori*, as well as a fourth category that emerged from the analysis. Each account documented the characteristics of the studies classified under that category, as well as the cognitive processes which the approach sought to facilitate.

In the *theory building* phase, a multiparadigm perspective was developed and the range of HCD studies was analysed as one complete data set. In particular, the degree of cognitive coverage possessed by existing HCD approaches was considered, in relation to previously documented criticisms and limitations of HCD. From this analysis, a central metaconjecture was induced regarding the opportunity to focus and expand upon the emergent Foundational Design category.

3 Groundwork

3.1 Defining the phenomena of interest

In this study, HCD is defined as the *design of software interfaces to exploit the users' existing natural or acquired skills and capabilities*. This approach, also referred to as 'user-centred design' (Hoffman et al., 2002), is an interface design philosophy that emerged out of the frustration associated with the machine and technology-oriented designs of the 1970's and 1980's (Van Dam, 1997). Such frustration led to the formalisation of the HCD concept by Norman and Draper (1986), which went on to become the dominant software design methodology as of the early 1990's (Seffah, 2003). As the HCD philosophy grew in popularity, a variety of methods for implementing it became common across the software design industry, and HCD became perceived to be an important means of enhancing usability (Roth et al., 2002; Karat and Karat, 2003). However, this preponderance of disparate methods makes it challenging to analyse HCD in an inclusive and meaningful manner. Thus, in order to holistically assimilate the diversity of human-centred research into this study, paradigmatic lenses for a metatriangulation will now be identified and focused.

3.2 Focusing paradigmatic lenses

The two dominant perspectives in Human Computer Interaction are those of engineering and cognitive science (Harrison et al., 2007). Hence, in this study two lenses are developed to correspond to these perspectives. Firstly, an engineering lens is used to identify taxonomies for the various engineering methods used in HCD, based upon existing classifications of interface design approaches presented in the literature. Following this, a cognitive science lens is used to analyse the underlying cognitive focus for each category of approach. In this way, the paradigm bracketing and bridging described by Lewis and Grimes (1999) may be performed, and the resulting analysis may identify areas of opportunity.

3.2.1 Engineering Lens

Norman (1988) described the process of software interaction design as the alignment of users' and designers' conceptual models, thus allowing users to accurately predict and assess the outcomes of their interactions. Norman (ibid, p.13) expands upon this by stating that "A good conceptual model allows us to predict the effect of our actions. Without a good conceptual model we operate by rote, blindly; we do operations as we were told to do them; we can't fully appreciate why, what effects to expect, or what to do if things go wrong". Numerous subsequent authors also built upon this idea of designing around the conceptual model, such as Cooper et al. (2003) and Shneiderman and Plaisant

(2005). In each of these accounts of software interaction design, the designer is tasked with ensuring that a user's conceptual model of the interface is *consistent* with the conceptual model the designer used to construct the interface. Grudin (1989) described three ways in which designers may go about achieving such consistency. These were *internal consistency within an application, external consistency with other application*s, and *external consistency with real world systems*. This triad identifies three distinct types of relevant conceptual model for designers and users, i.e. existing conceptual models of real-world systems, existing conceptual models of digital systems, and existing conceptual models for the system in question.

Grudin's description of three forms of consistency (ibid) provides a powerful conceptual starting point for the categorisation of engineering approaches. Firstly, designers may metaphorically liken the interface to an external real-world system, maintaining *external consistency with real world systems*. Assuming both designers and users possess a consistent conceptual model of the substitute system and that the implementation accurately captures this model, so designers' and users' conceptual models of the interface should also be consistent. Secondly, designers may liken the interface to existing digital systems to which users have already been exposed, maintaining *external consistency with other applications*. Again, assuming designers and users possess a consistent conceptual model of the existing digital system and the implementation accurately captures this model, designers' and users' conceptual models of the interface should also be consistent. Thirdly, instead of seeking to change users' existing conceptual models of the interface, designers may instead attempt to maintain *internal consistency within an application* by taking on these conceptual models as their own. These approaches resonate with other the accounts of design presented elsewhere in the literature, hence these three software interaction design categories, hereafter referred to as *Metaphoric Design* (MD), *Idiomatic Design* (ID), and *Contextualised Design* (CD), were adopted for the engineering lens.

3.2.2 Cognitive Science Lens

The engineering lens focuses on interface design approaches. However, the cognitive assumptions underlying the various HCD approaches must also be considered. Over the past couple of decades, a number of enduring problems in psychology have been reconsidered through the 'dual-processing' school of cognitive science (Benyon and Imaz, 1999). Dane and Pratt (2007) divided conscious and non-conscious processes into those within 'system 1', also referred to as automatic, tacit, natural, and associative, and those within 'system 2', also referred to as rational, deliberate, rule-based and intentional. Kahneman (2011) suggested an adversarial view of systems 1 and 2 could be helpful to understand human behaviour, which he allegorises as a 'psychodrama with two characters'. Yet this simplified two-part conscious/non-conscious system overlies what is generally accepted to be a more complex continuum of consciousness (Adam, 2008). Furthermore, it appears that processes of varying consciousness are fundamentally and inescapably interdependent. Evans (2008, p.270) noted that "all theories seem to contrast fast, automatic, or unconscious processes with those that are slow, effortful, and conscious". Similar conclusions are also evident elsewhere, as it has been observed that much of an individual's highly-conscious cognition is dependent upon, even perhaps a direct consequence of, accumulated less-conscious cognition (Bargh and Chartrand, 1999; Epstein, 2002). There have even been suggestions by Bargh and Ferguson (2000) that less-conscious processing may exhibit intentionality, as goal effects may influence even seemingly automatic behaviour. Lastly, distinctions are further complicated by the observation that cognition becomes decreasingly conscious for frequently encountered problems (ibid; Bargh and Chartrand, 1999; Kahneman, 2011).

In spite of these complexities encountered when attempting to isolate individual forms of cognition, a number of separable and distinct cognitive processes have been identified in existing cognitive science literature. Thus, the cognitive science lens in this study will seek to give form to the cognitive assumptions underlying each HCD engineering approach by identifying the specific types of cognitive processes to which they appeal. Thus, any neglected portions of the spectrum of consciousness may be identified, and it may be determined whether it may be of benefit to expand HCD into such areas.

3.3 Collecting the Metatheoretical sample

Eleven research outlets were selected for inclusion in this study. Firstly, as the Human-Computer Interaction (HCI) journal with the highest impact factor at the time of writing, *Human Computer Interaction* was included in the sample. Secondly, as described by Zhang and Li (2009), the AIS Special Interest Group on Human-Computer Interaction (SIGHCI) has been central to the development of the HCI aspect of Information Systems (IS) research over the past two decades. Therefore, all SIGHCI publications were also included, namely *ACM Transactions on Computer-Human Interactions, ACM Interactions*, and the *ACM SIGCHI Conference on Human Factors in Computing Systems*. In addition to this, SIGCHI has sponsored 12 special issues in a number of academic outlets, specifically the *International Journal of Human-Computer Studies* (2003, 2006), *Behaviour and Information Technology* (2004), the *International Journal of Human-Computer Interaction* (2005, 2008), the *Journal for the Association of Information Systems* (2004, 2006, 2008), the *Journal of Management Information Systems* (2005), *Information Systems Journal* (2008), and *The Data Base for Advances in Information Systems* (2008), as well as the aforementioned *ACM Transactions on Computer-Human Interactions* (2008). As a result, all of these journals were also considered important sources of HCD research and included in the sample. For each outlet, publications over the last ten years (i.e. since 2001) were considered. An exhaustive search within theses outlets was performed for articles with the words 'human centred/centered design' and 'user centred/centered design' in the title, subject terms or abstract. This yielded a total of 144 papers. The sampling criteria also demanded that articles described some approach to software interface design, rather than merely describing issues in HCD, reviewing other secondary sources, or discussing non-interface related design projects. On these grounds, 32 of the 144 papers initially in the sample were omitted. The remaining 112 articles were placed in the category which best captured their design prescriptions, as per the engineering lens. It was also observed during analysis that studies focussed upon different stages of development, i.e. pre or post instantiation. This is significant for any design approach, as it impacts upon the cost and likelihood of implementation (Holzinger, 2005). Hence, this aspect of each article was also noted.

4 Data Analysis

4.1 Writing paradigm accounts

This section presents an account of each HCD engineering approach. These accounts were written in order to perform the paradigm bracketing described by Lewis and Grimes (1999), and develop a cohesive understanding of the individual characteristics of each engineering category. Each account documents the basic defining features of the approach, variation observed within these features, and the cognitive processes which it seeks to address. The distribution of the literature according to these paradigms is presented in Table 1.

4.1.1 Metaphoric design (MD)

Interface metaphors have been a central feature of HCD, credited with reducing a number of usability barriers (Nardi and Zarmer, 1993; Bryant, 2000). Norman and Draper (1986) described this aspect of interface design as 'mimetic', whereby an application can allow interactions to correspond to more familiar real-world interactions common to users. Bryant (2000, p.280) claimed that "… there is now a widespread view that metaphors play an active role in thought and cognition. In particular, metaphors are now seen as a crucial aspect in the spread and understanding of new ideas and concepts". Whilst an appropriate metaphor may provide significant benefits, finding this 'metaphor-theme' presents significant challenges, as it must be both familiar to all users, as well as being sufficiently 'strong', in the sense that negligible rules violations occur (Black, 1977). Indeed, a number of studies focused upon actively involved users to determine an appropriate metaphor, e.g. Koleva et al.'s (2009) search for an appropriate set of metaphors for an art exhibition, or Rullo's (2008) design of a neonatal unit with appropriate aesthetic and affective properties.

Lakoff and Johnson (1980, p.5) stated that "the essence of metaphor is understanding and experiencing one kind of thing in terms of another". In this way a new *target* object's characteristics may be inferred from some already understood *source* object. From the perspective of the cognitive science lens, this target-source method draws upon the cognitive processes described by Klein (1993) as 'recognition-primed decision making'. In such a case, the user utilizes a broad but incomplete understanding to make trial and error style mental simulations of past and future states, such that the best course of action can be taken. Comparisons may also be made with Simon's (1979) idea of 'bounded rationality', whereby an application is assumed by designers to be too complex to expect users to grasp in its entirety, so users are endowed with an imperfect metaphor such that they can interact within a harmlessly bounded understanding (Kuhn, 1993; Benyon and Imaz, 1999).

4.1.2 Idiomatic Design (ID)

The central motivation for ID is the transfer of learning across from established software applications to new applications and to this end, two forms of idiomatic design are evident in the sample literature. The first of these is concerned with identifying and applying suitable design standards, such as Reinecke et al.'s (2011) culturally adaptive user interfaces or Newell et al.'s (2006) examination of the impact of mainstream idioms on older users. The second form of ID was slightly different, in that it drew upon a product family. For example, Sawin et al.'s (2002) description of the accumulation of interface standards in the IBM ThinkPad series, or Healy and Herder's (2002) evolution of browser-based information system from Winter Olympic Games in Japan 1998 for Sydney 2000.

When Cooper et al. (2003, p.250) described certain interfaces as 'idiomatic', they illustrated that the meaning of these items does not have to be sensible in the same way a metaphor does, stating "*If you cannot intuit an idiom, neither can you reason it out. Our language is filled with idioms that, if you haven't been taught them, make no sense... This is a necessity, because most idioms don't have metaphoric meaning at all, and the stories behind most others were lost long ago*". Viewed through the cognitive science lens, it is observed that this process differs from the abstract comparative problem-solving processes exploited by MD. Indeed, ID is more likely to draw upon the cognitive processes described by Aamodt and Plaza (1994, p.39-40) as 'case-based reasoning', whereby users are "able to utilize the specific knowledge of previously experienced, concrete problem situations (cases). A new problem is solved by finding a similar past case, and reusing it in the new problem situation". Furthermore, it may also appeal to the definition of 'insight' provided by Dane and Pratt (2007, p.40), where one "consciously becomes aware of the logical connections supporting a particular answer or solution".

4.1.3 Contextualised Design (CD)

The concept of 'cognitive coupling' in software design emerged with the subfield of cognitive ergonomics in the early 1980s, in parallel with the HCD philosophy (Bannon 1991). This concept, based upon the principle of aligning software design with the existing conceptual models of users, often provides the motivation for the participatory approaches commonly associated with HCD endeavours (Vrendenberg et al., 2002; Hoffman et al., 2002; Karat and Karat, 2003). As noted already, what marks CD as unique amongst the three categories of design, is that designers are not seeking to change the user's conceptual model of an application. Instead, they seek to understand the user's existing conceptual model and design the interface around that. As a result, it becomes crucially important that designers' understanding of the user is accurate. Hence, whilst MD and ID may or may not involve active user participation, the CD studies always relied upon having some access to actual typical users, in order to ensure their understanding of the user was adequate. This participation ranged from the heavily immersed grounded-theory-based persona-developing ethnography of Faily and Flechais (2011), to the iterative evaluation-based improvements advocated by Wright et al. (2008).

Approach Type	Metaphoric Design	Idiomatic Design	Contextualised Design
Description of Approach	Designers liken conceptual model of the system to other existing real world systems	Designers liken conceptual model of the system to existing digital systems	Designers liken conceptual model of the system to existing conceptual model of users
Literature where prescriptive findings focus on pre-instantiation	Burnett and Porter 2001, Scaife and Rodgers 2001, Sedig et al. 2001, Stone 2001, Stedmon and Stone 2001, Svanaes et al. 2001, Hudson 2002, Palen and Salzman 2002, Jeng-Yi 2004, Whittaker et al. 2004, Patel et al. 2006, Plaisant et al. 2006, Sutcliffe et al. 2006, Tan et al. 2006, Sundström et al. 2007, Tang 2007, Redström 2008, Rullo 2008, Zhao 2008, Hundhausen et al. 2009, Loke and Robertson 2009, Lysecky and Vahid 2009, Paay et al. 2009, Salom et al. 2009, Kjeldskov and Paay 2010, Benford et al. 2011, Bowen and Petrelli 2011, Kühnel et al. 2011	Lindgaard et al. 2001, Zhang and Salvendy 2001, Øritsland and Buur 2003, Seffah 2003, Bell et al. 2005, Newell et al. 2006, Corter et al. 2007, Hartmann et al. 2008, Iachello and Abowd 2008, Chevalier et al. 2009, Paterno et al. 2009, Shaer and Jacob 2009, Kostakos et al. 2010, Rhee et al. 2010, Reinecke et al. 2011, Zimmerman 2011	Bruseberg and MCDonagh-Philp 2001, Earthy et al. 2001, Lacohée and Anderson 2001, Leela 2001, Maguire 2001a, Maguire 2001b, Parker and Sinclair 2001, Bødker and Buur 2002, Catarci et al. 2002, Johnson and Hyde 2003, Karat et al. 2003, Oviatt et al. 2004, Karat et al. 2005, Gaunet and Briffault 2005, Gross et al. 2005, Marcus 2005, Robertson 2005, Wiberg and Whittaker 2005, Dey and Guzman 2006, Lewis 2006, Biehl et al. 2007, Zhou et al. 2007, Bailey and Iqbal 2008, Bardram 2009, Collins-McLoughlin et al. 2009, Holtzblatt et al. 2009, Hudson 2009, Neustraedter et al. 2009, Chen and Pu 2010, Robins et al. 2010, Faily and Flechais 2011, Ni et al. 2011
Literature where prescriptive findings focus on post-instantiation/ prototyping	Burmester et al. 2002, Kline and Seffah 2005, Medhi 2007, Koleva 2009	Danesh et al. 2001, Sobiesiak et al. 2002, Cockburn and Gutwin 2010	Hall 2001, Maguire 2001c, Ominsky et al. 2002, Healy and Herder 2002, Herbsleb et al. 2002, Sawin et al. 2002, Siegel and Rouchka 2002, Pinelle et al. 2003, Sperschneider and Bagger 2003, Wixon 2003, Benford et al. 2005, Ben-Bassat et al. 2006, Dinka and Lundberg 2006, Marcus and Gasperini 2006, Venturi et al. 2006, Hornbæk 2006, Wolf et al. 2006, Carter et al. 2007, Mills 2007, Nivala et al. 2007, Rittenbruch et al. 2007, Blandford et al. 2008, Wright et al. 2008, Civan-Hartzler et al. 2010, Iqbal and Bailey 2010, Verhoeven et al. 2010, Chilana et al. 2011

Table 1. *Breakdown of the Human-Centred Design literature within the sample range of years and journals, according to the engineering lens developed in 3.2.1. A complete bibliography for the sample literature was not included due to space restrictions but is available from the authors upon request.*

At a cognitive level, the need for direct user participation is premised upon the assumption that users are not sufficiently consciously aware of certain preferences, thus are unable to make them explicit to designers (Büscher et al., 2001; Harrison et al., 2007). It is this lack of awareness that makes CD distinct at a cognitive level from ID. Bargh and Chartrand (1999) proposed that individual prejudices, managed less-consciously by ‘mental butlers’, determine a large amount of everyday activity for human beings. Consequently, the cognitive science lens reveals that the types of cognition which CD seeks to assimilate into design are what Dane and Pratt (2007, p.40) describe as ‘intuitive’, namely “affectively charged judgements that arise through rapid, nonconscious and holistic associations”.

4.1.4 Foundational Design (FD)

A key output of the analysis emerged in the form of a fourth engineering category. This category contained only three articles but differed significantly from each of the initial three, as it did not focus upon a conceptual model in any capacity. Instead, each paper drew upon *early perceptual* and *pre-judicial* aspects on interaction. Interestingly, it could be argued that the FD category represents a move towards the software design research which predates HCD (c.f. Shneiderman and Plaisant, 2005). DeBruijn and Spence (2008) develop Design Actions based on theories of visual processing from cognitive science, in order to aid serendipitous information retrieval. Similarly, Hitchcock et al. (2001), advocate age-inclusive designs which consider common ergonomic issues for older users, such as an inability to perceive certain colour combinations or sensitivity to rapid alterations to light. Lastly, Dai et al. (2009) focus upon harnessing the high human capacity for recalling information with minimal cues, in order to compensate for compromised data accuracy. These studies differ from previous categories, in that they exploit more animalistic and less deliberate cognitive processes, of which users are usually not aware. Thus, the cognitive science lens reveals FD focuses on the type of processes Dane and Pratt classed as ‘guessing’ or ‘instincts’, i.e. “innate capabilities that originate outside the experiential processing system” (Dane and Pratt, 2007, p.40).

5 Theory Building

5.1 Attaining a multiparadigm perspective

The distribution of literature showed that 57 papers were CD (51%), 32 papers were MD (29%), 19 papers were ID (17%) and only 3 papers were FD (3%). None of these categories appear to be rapidly gaining or losing popularity, as demonstrated by a Kruskal-Wallis test for comparison of the design categories and publication years between the groups, $\chi2(3) = 1.965$ and $p = 0.58$. The most popular journal for HCD publications was *ACM Transactions on Computer-Human Interaction* with 43 papers (39%), whilst no HCD papers were found at all in 4 of the 5 mainstream IS journals (the exception being *Behaviour and Information Technology*, in which 3 HCD papers were found), suggesting that HCD is not a topic widely embraced outside of the Human Computer Interaction sub discipline. It is interesting to observe that the majority of research (70%) offered design prescriptions which were applicable prior to an instantiation of the interface. This is likely because of the added expense and resistance encountered when changes are attempted later in development (Holzinger, 2005). As with the engineering categories, there is no significant evidence that this trend towards pre-instantiative design prescriptions is gaining or losing popularity across the ten publication years, Mann-Whitney $U = 12.5$, $p = 0.23$. However, it is noteworthy that an association between the engineering category and whether research provided pre-instantiation design prescriptions or post-instantiation design prescriptions was found, $\chi2\ (3, N = 111) = 14.5$, $p = 0.002$. This confirms the visual information provided in Table 1 that a far greater proportion of design prescriptions from CD research is post-instantiative (46%, as opposed to only 7% of the other categories). Such a finding may be because of designers struggling to understand specific users’ conceptual models until they have a concrete example of an interface to provide a shared vocabulary and act as a conceptual proxy.

Having performed paradigm bracketing and written accounts of each individual HCD approach, paradigm bridging must also be employed in order to make the 'creative leaps' required to build new theory (Lewis and Grimes, 1999). Each of the three engineering categories identified prior to gathering the literature sample focused upon conceptual models possessed by users. The cognitive science lens demonstrated that these three engineering categories focused on cognitive processes towards the more conscious end of the spectrum (see Figure 1). In terms of the cognitive processes defined by Dane and Pratt (2007), Adam (2008), and Simon (1979), the only highly-conscious process to be omitted by MD, ID and CD was 'rational decision making', the actual existence of which Simon (ibid) contests. Yet at the less-conscious end of the spectrum, both 'guessing' and 'instinct' did not feature, except in the emergent but sparsely represented FD category. This illuminates a significant under-exploitation of the least-conscious cognitive processes in popular HCD approaches, as less than 2% of the sampled HCD studies focused upon such cognition.

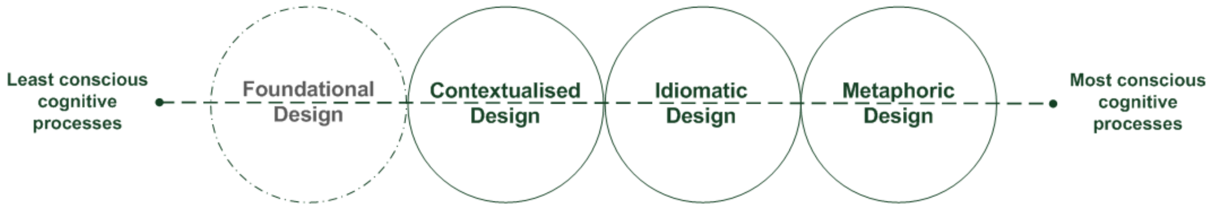

Figure 2. Existing Human-Centred Design approaches and their areas of cognitive focus

5.2 Exploring metaconjectures

The most striking issue identified by the analysis is HCD's reluctance to exploit the least conscious cognitive processes. This is a significant finding in the context of the criticisms of HCD already observed. Norman's (2005) asks the rhetorical question 'what happens when a product is designed to be used by almost anyone in the world?' Indeed, Norman (ibid) suggests that 'true human-centrism' is impossible as a result, and posits this fundamental problem as motivation to abandon HCD for activity-centred approaches. However, the FD category of HCD research that emerged during analysis presents an alternative less drastic solution to this problem. In each of the three conceptual model-based approaches, an attempt is made by designers in some shape or forms to anticipate users' understanding of the world. This understanding is learned and experience-based, hence will vary from individual to individual. Therefore, with the conceptual model-based approaches, wide-ranging human-centrism is indeed impossible. However, whilst people will differ in their highly-conscious cognitive processing, their less-conscious patterns often remain consistent (Baars, 2002; Koch, 2004). This leads to the central metaconjecture to result from this study, i.e. that *design approaches focused upon less-conscious cognitive processes offer an opportunity to obtain the elusive form of widespread human-centrism lacking in contemporary mainstream interface design*.

6 Foundational Design: A Future Research Agenda for HCD

This study has made a number of important contributions. First, the systematic categorisation and analysis of HCD research has facilitated a clearer understanding of an important but potentially nebulous topic. These categories are by no means exclusive and are frequently applied in combination, yet each is motivated by a desire to target different cognitive forms of cognition. Second, the multiparadigm perspective on HCD research has brought to light the cognitive coverage of various HCD engineering approaches. Third, the study affirms the dominance of CD within the HCD literature, and notes that, although the majority of HCD studies provided design prescriptions which could be applied pre-instantiation, this was less true of CD approaches. Fourth, the study revealed that HCD research is not a topic widely researched in mainstream IS outlets. Why this should be the case is not clear, given that issues such as technology adoption and diffusion are central for IS researchers. Each of these newly observed trends in HCD warrants further investigation.

However, the primary contribution of this paper is the central metaconjecture emerging from the study, namely the need for researchers and practitioners to move the focus of HCD away from currently popular design approaches, based upon conceptual models and highly-conscious cognition, and towards emerging design approaches based upon less-conscious cognitive processes (e.g. FD). These new approaches, used in conjunction with more traditional HCD methods, afford a means of increasing user-independence and exploiting a more complete range of human cognition. This metaconjecture resonates with the outcome of an AIS 'Foundations of NeuroIS' retreat held in Gmunden in 2009, which identified the interface as one of the areas of unfulfilled potential for the application of neurological theories (Riedl et al., 2009). Indeed, although the emerging NeuroIS stream is not frequently discussed in existing HCD literature, conceptual parallels with FD are both intuitive and useful. A vast number of well supported neurological theories exist as regards the evolutionary human processing of visual, audio and haptic sensory input. In particular, given the visual nature of the interface, the assimilation of visual theories into software interaction design appears promising, as demonstrated already by DeBruijn and Spence (2008). For example, NeuroIS theories may inform our understanding of the impact of various colours and shapes on item perceptibility, interface affectivity, or even the impact of interface luminescence on alertness. Similarly, neurologically-grounded theories of memory may allow for more easily learned feature hierarchies. Design theories exploiting less-conscious audio and haptic processing are also increasingly relevant in the face of calls for environmental interfaces being made by scholars such as Dey and Guzman (2006). In each of these areas of cognition, the potential gains of a greater exploitation of less-conscious processing are significant, as more efficient 'automatic' cognition is not only likely to benefit interaction directly, but also indirectly by providing a faster platform for inter-reliant highly-conscious processes, e.g. by making semantically relevant items more perceptible or by increasing affectivity to encourage users to invest effort learning the software (c.f. Tractinsky, 2004). It is noteworthy that on-going experience with a given tool decreases the consciousness of interaction (Bargh and Chartrand, 1999; Kahneman 2011). Thus, the temptation may be to argue that HCD need not target less-conscious processes directly, as efficient less-conscious interaction occurs naturally over time. However, this would mean less-conscious processes are only facilitated after long periods of interaction, not during the crucial learning period or for users undertaking less prolonged usage.

It is acknowledged that, although 'true human-centrism' is the central motivation for the proposed change in focus in HCD, in practice exceptions will likely always exist, particularly when physical or psychological disabilities are accounted for. For example, a severely visually impaired user is unlikely to benefit from designs for a visual interface, regardless of whether they are based on model-based or neurological theories of vision. However, such limitations do not render void the goal of 'true human-centrism', just as the untenability of a world utterly free of violence does not render void the goal of social harmony. The measure for success in the HCD paradigm is the extent of human-centrism, and FD research offers a vital means of radically increasing it. So much of human interaction with the digital world harnesses uniform visual, audio and haptic cognitive processes, that it is unacceptable our academic discipline should continue to overlook them. This will present a new challenge for HCD researchers, many of whom possess a strong understanding of model-based psychological theories but far less knowledge of neurological research. Furthermore, the methodology of extracting prescriptive design theories from cognitive neuroscience remains to be developed to the same degree. However, the existence of some FD research currently in circulation, as well as the emerging NeuroIS stream, demonstrates that this transition, although difficult, is possible. The design science methodology in particular appears to offer a promising means of generating prescriptive design theories, utilising cutting-edge research from cognitive neuroscience as kernel theories. Indeed, if such a move is not undertaken, then HCD may find itself confined to the annals of history, just as the machine-oriented interfaces of the 1970's. We thus call for further FD studies, which expand current HCD practices with concrete software interface design guidelines to facilitate less-conscious cognitive processes.

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