Ghosts in the Machines: Towards a Taxonomy of Human Computer Interaction

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Abstract. This paper explores a high level conceptualisation (taxonomy) of human computer interaction that intends to highlight a range of interaction uses for advanced (symbiotic) systems. The work formed part of an EC-funded project called CEEDs which aims to develop a virtual reality based system to improve human ability to process information, and experience and understand large, complex data sets by capitalising on conscious and unconscious human responses to those data. This study, based on critical and creative thinking as well as stakeholder consultation, identified a range of variables that impact on the types of possible human computer interaction, including so called 'symbiotic' interactions (e.g., content displayed – raw/tagged; user response – explicit/implicit; and whether or not there is real time influence of user response on content display). Impact of variation in the number of concurrent users, and of more than one group of users was also considered. This taxonomy has implications for providing new visual stimuli for creative exploration of data, and questions are raised as to what might offer the most intuitive use of unconscious/implicit user responses in symbiotic systems.

Keywords: Symbiosis · Symbiotic · Human-computer · Interaction · Technology-mediated · Taxonomy · Classification · Presence · Interaction design · Affective systems · Intuitive interaction · Attention · Mediated · Displayed · Environment · Confluence

1 Introduction

The quality and forms of technologies to support interactions between people and computers have markedly increased in recent years, from simple pointers, navigators and button click inputs to more natural and intuitive, even immersive, controls. Interactions with technologies can be experienced as an extension of the self, typically through increased experience/practice, for example, driving a car. However newer technologies are attempting to remove the 'translator' in the mechanics and plug more directly into our conscious as well as unconscious perceptions and intentions offering the potential for a truly seamless, transparent experience.

Intuitive interactions enable increased focus and immersion in the task to hand, reducing the division in attention between the primary (target) and secondary (machine interaction) tasks. Indeed the term 'presence' has been used to describe this subjective

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sense of ‘being there’ in a mediated/displayed environment (e.g., Barfield et al. 1995) and is often used to measure perceived quality of experience of a displayed environment (e.g., Lessiter et al. 2001). In these contexts, distractions emerging from the ‘real world’ can include clumsy and awkward system interactions that demand user attention and break the spell to mediated presence. Identifying ways of minimising distractions or at least their impact on both the user and the machine is important to the fluidity, meaningfulness and accuracy of inferred experience.

A high level conceptualisation of human computer interaction would benefit our understanding of the usage possibilities within this new genre of what might be called ‘symbiotic systems’. This paper describes one such interaction taxonomy informed by consultation with stakeholders, and critical and creative thinking. The work was born out of an European Commission (FP7 FET) funded project called CEEDs – the Collective Experience of Empathic Data systems - which explores the potential for both conscious and unconscious (multi-)user control over displays of complex data.

2 Classifying Human-Computer Interactions

The term ‘taxonomy’ originated in the biological sciences. Taxonomies have now extended to any “ordered classification, according to which theoretical discussions can be focused, developments evaluated, research conducted, and data meaningfully compared” (Milgram and Kishino 1994, p. 1323). Such classifications can shed light on the critical and optional parameters that can serve to enhance or reduce the quality of experience of that human computer interaction.

There are taxonomies for various types and aspects of human-computer systems which can make it difficult to compare and pool these specific taxonomies as the extent to which they overlap is unclear (von Landesberger et al. 2014).

From a more general perspective, Parasuraman et al. (2000) provided a framework for dynamic function allocation systems (following the traditional trajectory of HCI) comprising a dimension of automation ranging from fully automated to fully manual for each of four categories of function: (a) information acquisition; (b) information analysis; (c) decision and action selection; and (d) action implementation. However, this type of classification does not clearly address systems which may not seek to replace effort on behalf of the user, but rather complement or harness human efforts at different levels of our awareness as may be the case with systems that aim to be symbiotic.

3 Human-Computer Symbiosis

Symbiosis traditionally denotes the relationship between two or more organisms ‘living together’ in a mutually advantageous manner. In an HCI context it similarly suggests a mutually complementary understanding between entities (e.g., Licklider 1960; Grootjen et al. 2010; García Peñalvo et al. 2013) that builds and grows with each interaction. Indeed, relationships that are truly symbiotic are expected to be experienced as natural, fluid and intuitive.

How this might be achieved raises questions about how we make sense of ourselves and how we believe that systems will be able to understand and make sense of us. Consequently, what user data and processes (e.g., sequences of action) are important and what could be inferred from them? Further, in what contexts or scenarios could these symbiotic relationships with computers be of particular advantage? And importantly, how might users experience symbiotic relationships with computers, given that this is a new type of human-computer interaction? Theoretically we imagine it will feel seamless and natural but until these systems are tried, tested, technologically optimised, and users become more familiar with their implementation, it is unclear how users will initially experience and respond to them.

There are numerous projects that have developed or are developing applications of symbiotic systems that aim to improve *relevance* of system outputs to user requirements, for instance of literature searches (e.g., EC MindSee: see www.mindsee.eu), product recommendations (e.g., Adidas-Intel's 'adiVerse'), games (e.g., Kinect 2 and Valve, both of which make use of physiological responses to influence game play), and vehicles (e.g., AutoEmotive).

Applications are naturally variable in the quality of the interaction/symbiosis depending on the validity (meaningfulness) and reliability (accuracy vs. uncertainty and consistency) of the user data that are selected, how inferences are made by the system and the timeliness of the system's response. In today's world, massively multivariate data are being collected at an unfathomable rate and yet are neither fully understood nor exploited for advantageous benefits to ourselves and wider society. Of course human-computer interaction quality is currently dependent on, and is limited by, what we can tell machines about ourselves and how to learn about us. We are limited by our sensory, perceptual and cognitive abilities, and by the engineered tools we have creatively constructed throughout our evolution to support our capacity to understand the world. But what if new technology can help us exploit previously unexplored territories that reside in our bodies as extensions of our interaction with the world? Eventually machine learning and its application in symbiotic systems may supersede our current creative capacity in as early as 2021 as predicted by Vinge (2006) (cited in Grootjen et al. 2010).

3.1 Symbiosis in Context: The CEEDs Project

The Collective Experience of Empathic Data Systems (CEEDs) project commenced in 2010 and aims to address the data deluge problem which includes symbiotic man-machine interactions. It proposes to develop a virtual reality based system to improve human ability to process information, and experience and understand large, complex data sets by capitalising on conscious and unconscious human responses to those data (see: ceeds-project.eu; e.g., Lessiter et al. 2011; Pizzi et al. 2012; Freeman et al. (2015)).

Central to the symbiosis is having the interaction between representations of two entities that have intent to make sense of the other, mediated by a 'sentient' autonomous agent. The representation of the 'human' (to the computer) relates to the physical, observable manifestations of the user's self that the computer is watching (user responses). The computer represents its 'self' through sensorial information to be solved (the task related data – the data deluge) that is amenable to human detection (visualisation e.g. patterns) at varying levels of awareness. This is how the entities exchange information and the system and user become "confluent into a symbiotic cooperation" (van Erp et al. 2010, p. 202).

The CEEDs system is a type of dynamic/adaptive visual analytic as it primarily represents its understanding of the user's intentions to explore the data visually: what patterns do users notice/respond to and why? And how should the system appropriately respond to support increased user understanding, discovery and creativity? Such systems capitalise on human cognition (e.g., perception and decision making) and machine based data processing, analysis and learning, providing a bridge between exploration and analysis (Endert et al. 2014). How quickly the system responds to user interactions can also pose a technical hurdle to the fluidity and perceived symbiosis of the experience.

In the early stages of the CEEDs project, development of use cases and scenarios was required across a wide range of potential application domains: big visualised data in the areas of neuroscience, history, archaeology and design/retail (commerce). To this end, system commonalities across application scenarios were sought based around possible ways in which users' responses may be used as inputs and outputs in any CEEDs application. A taxonomy or classification system of human computer interaction that included symbiotic data exchange was required.

4 Method

To inform the development of the taxonomy of interaction uses, stakeholders working within each of the target application domains were consulted. Along with pragmatic questions relating to the types of data used in their big data field, they were asked to (qualitatively) comment on the relevance of the initial aims of CEEDs, as stated in the project's Description of Work document for their specific application area, and to suggest other goals they envisaged being met by CEEDs.

The objective was to gather as many user requirements as possible which would provide a wide range of material to refine and elaborate a smaller selection of higher level uses that were deemed valid, symbiotic, in-scope of the project and could be developed as prototypes. Having a wide application remit was useful for developing a taxonomy of interaction uses that was general enough to apply across different contexts.

Replies were received from seven stakeholders around half of whom were project partners. Responses included five university departments, one historical museum/ memorial site and a 'white goods' manufacturer. The majority were academics.

Critical and creative thinking was used to identify underlying processes and/features that may vary in one type of interaction experience to another.

5 Results

The contextualized potential applications of CEEDs derived from the Description of Work and stakeholder feedback were explored for interaction styles and themes. Across the application areas, there was also some broad consistency in the goals that CEEDs technology could support. For instance, CEEDs supports insight and adaptability to users' responses to data which makes it a useful tool for the following interrelated uses:

- discovering unknown relationships (e.g., between user responses and stakeholder data i.e., adding metadata to stakeholder databases)
- personalising experiences (e.g., refining choices)
- validating relationships (e.g., best fit)
- representing relationships (e.g., reviewing data)
- optimising experiences to a given construct (e.g., influencing others, learning sequences of actions, improving memorability of information, optimising enjoyment/presence).

Some stakeholder goals/requirements indicated a distinction between (a) (primary) CEEDs end users – users/interactors and (b) (secondary) CEEDs beneficiaries – CEEDs system data owners. (Primary) CEEDs end users are those who use and interact with the system. For instance, customers are supported in their product choices by CEEDs offering a personalised service based on their own (stored and/or real time) unconscious desires and preferences. As an alternative example, consider a team of neuroscientists attempting to validate/refute models to explain patterns of data. They are supported in this discovery process by CEEDs technology because it harnesses their unconscious responses to different visualisations of those models with the data. The neuroscientists can test these models for unconscious 'goodness of fit'. Primary CEEDs end users could be both expert/professional users as well as novices.

Other stakeholder goals suggested that some CEEDs users could be more correctly classified as CEEDs beneficiaries as they are (secondary) CEEDs users of others' data. These are characterised as CEEDs system/database owners and can analyse end user responses to data in all sorts of ways. Beneficiaries could use CEEDs user data to optimise displays for different goals (e.g., learning, empathy, sales); predicting and influencing a users' behaviour by understanding their states/plans/intentions in a given context. For instance, design teams may be beneficiaries if they explore their customers' implicit reactions to products to improve product design. Most users in this category were experts/professionals.

5.1 Components of Symbiotic Human-Computer Interaction

A taxonomy of these different types of human computer interaction/symbiosis within a CEEDs context was developed that identify a number of dimensions or factors which may change from one experience to another.

Three main entities were considered relevant in the context of inputs and outputs in the human computer interaction, namely: the user, the 'CEEDs engine' (a sentient autonomous agent/computer), and the content/data display through which the computer relates to the user (see Fig. 1).

The taxonomy assumes that any data displayed will have meaning. There are two main sources of data: the raw data (that comprise the data deluge) and response data from the user. The raw data (before any users have experienced and responded to it) is visualised, potentially represented in other modalities, and 'produced' or contextualised before it is presented to a user: the raw data will not appear as the database itself.

In this conceptualisation of symbiotic interaction, user response data (to the presentation of the raw data) are recorded and annotated into a copy of the raw dataset. For instance data recorded may include what the user response was (e.g., a smile, a vocal command, pupil dilation), to what specifically in the display, for how long the user response lasted, and the inferred meaning (interpretation) of the single/combined user response(s). This process of recording and storing user response data is termed 'tagging' here.

The taxonomy includes variation in (a) the nature of the content displayed (raw or pre-tagged data), (b) whether or not current users' implicit/explicit data are measured/monitored, and (c) whether or not there is any real time feedback from the system to user responses (in whatever form that feedback might take). Additionally there are example representations of multiple users in any session. Varying these characteristics produces a wide range of interaction possibilities, the outputs of some of which are difficult to imagine and remain to be explored from a user experience perspective. Crucially, the displays of those datasets (raw and user) can be combined in different ways to produce novel outputs that users can either view and/or actively explore. For further information about the core features of the CEEDs system, see Freeman et al. (2015).

In the pictorials that were developed to accompany the taxonomy (nb. The full set of pictorials are beyond the scope of this position paper), the three entities are contained within a larger boxed space indicating the 'current session'. In its simplest use, the content display reflects variation in the task related dataset to be explored (raw data). But with no feedback from the user, this provides a passive mode of operation (merely 'viewing') akin to television watching (see Fig. 1).

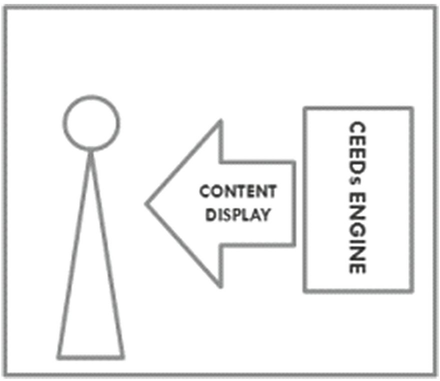

Fig. 1. Three components of human computer interaction: passive viewing

5.2 Active and Passive Interactions

In a fully interactive technology-mediated experience, the content display presents variation in both the raw data, and the CEEDs engine's real time reflection of its understanding of the current user (the user dataset/model). Its understanding develops with each interaction by the user with the data displayed.

Of course, there are also many possible viewing experiences that are passive for the current user whereby they have no real time explicit or implicit control over the content display. For instance, in a passive mode, it is possible that (a) the current user response data is nevertheless being collected albeit not represented whilst ‘viewing’ and/or (b) the data displayed to the current user might already be an amalgamation of raw data and user data (e.g., experiencing someone else’s visual experience of the data, or indeed one’s own experience from a previous session). These technology mediated experiences, whilst passive, may also provide visual stimuli that inspire insightful explorations of data. The style of interaction between the human user and computer (CEEDs engine) via the content display is therefore related to the presence or absence of real time or delayed explicit and implicit user response feedback to the system.

5.3 Types of User Responses

The more the user is physically immersed and feels present in the displayed experience, the more accurate the user model that can develop. User responses collected by the system are ideally in response to what is displayed and not caused by extraneous uncontrolled events outside of the displayed world. This underlines the importance of the fluidity and usability of the user’s explicit means of controlling the display particularly with regard to naturalness of (expected) interaction.

‘Explicit’ (user) responses refer here to overt, deliberate ‘conscious’ responses. These include behavioural responses such as gesture, pointing, verbal responses/speech, button pressing, manipulation of tangible representations and motion/trajectory. It is expected that the user’s sense of symbiosis will increase with improvements in the accuracy and attentiveness of the CEEDs engine and naturalness of expected response of the display (output) to users’ explicit responses (inputs). This relies on the system understanding what users consider appropriate and expected. This area is generally well understood in HCI.

In contrast, user responses are called ‘implicit’ when they refer to covert, uncontrolled responses that are ‘unconscious’. These could be physiological (e.g., ECG, respiration, EDR, EEG, EMG, pupil dilation) or behavioural (e.g., blink rate, eye-tracking, reflexive postural and physical responses, vocal emotion). Unlike explicit user responses, it is not yet clear how users might expect the display to ‘intuitively’ respond to their own implicit responses to the content display and indeed how this impacts on subsequent explicit and implicit action loops. How will we make sense of being faced with our own responses that previously lay beneath our conscious awareness?

5.4 Key Variables in Human-Computer Interactions

In this initial taxonomy of human-computer (symbiotic) interactions, user responses that are implicit or explicit can be relevant, or not, to any particular CEEDs session. User response feedback in the current session can be real time or derived from a previous interaction with the same or a different user's response data. Thus user response data can be collected without having real time impact.

Where a previous user session's data is relevant, data displayed in the current session have 'pre-tags' based on those responses of users from previous sessions (which may or may not include previous experiences of the current user with that raw data). It may be possible for a current user to be presented with pre-tagged raw data (derived from a previous session) as well as real time tags based on the current users' responses. For instance, a designer may wish to explore using explicit responses (e.g., gesture) the data of a target user who has previously explored the latest of their product designs to understand which aspects of the product were particularly noticeable and liked by the user.

5.5 Passive Interactions and Example Uses

Passive interaction examples are those in which the user cannot influence the display in real time (no user feedback of explicit and/or implicit responses). However, it is possible that the current user's implicit and/or explicit response data are nevertheless being captured and tagged on to the raw dataset. This tagged data could then be explored by the same/another user at a different session. An example of this type of scenario would be circumstances where it is important to control presentation of (inert/moving) stimuli so that multiple users' responses to standardised (identical) stimuli can be collected and later reviewed.

In this type of 'review' scenario, a previous user's data are 'overlaid', tagged or have influenced the way in which raw data is presented. The current user's responses to those tagged raw data are inconsequential if their responses are not being collected.

In another scenario the current user could experience 'tagged' raw data, and whilst their own explicit and/or implicit responses may be collected and stored, they may have no real time influence on the display. This could represent a current user's experience of data that has been optimised for a given construct (e.g., learning) based on a previous user's data and for which the beneficiary (e.g., an expert) is testing the effectiveness of this representation with the current user.

5.6 Active Interactions and Example Uses

There is a range of potential active interaction experiences. In all examples, raw data is influenced in real time by the users' own implicit and(/or) explicit responses. This relies on the computer (in this instance, the CEEDs engine) to develop a user model based on user responses to data displayed. Its user model influences the display to support the goals of that experience (e.g., learning, maintain a particular level of arousal).

A user could have real time influence over their experience of pre-tagged stakeholder data. This scenario is relevant where the goal is to reinforce or strengthen associations between multiple serial/concurrent users' responses and the representations in the stakeholder dataset.

Any CEEDs active interaction session could take place with single or with multiple concurrent users. For instance, multiple concurrent users could provide their own responses to pre-tagged raw data. These possibilities raise issues about how the computer will deal with user data from multiple simultaneous inputs. For instance, a teacher in training their students to look for significant patterns in raw data may require that the computer weights the group responses (and thus, the influence on the display) to that expert's response data.

More complex human-computer symbiotic interactions are possible. For instance two groups of remotely located users (explorers and evaluators) could interact with the same dataset: evaluators observe in real time how the explorers react to the data. If evaluators' explicit responses are weighted in their favour they are given more control over the display through their explicit reactions. In the CEEDs system, members from both groups are considered as part of one group (only the applied weighting/roles will vary). An example might be that the evaluators are a product design team that has some explicit control over how the explorers are experiencing a product. For instance, they might (explicitly) command the system to direct the explorers' attention in real time to a new design feature to better understand how users respond to it.

There are further possible types of very complex interactions to be explored using this taxonomy. A flavour of what might be possible has been provided in the examples considered here. Whilst this taxonomy served the purpose of supporting the definition of what is a CEEDs experience, its generality to a wide range of other interactive systems remains to be tested. Further, as highlighted by Nickerson et al. (2013), taxonomies of information systems that have been conducted often fail to apply a rigorous methodology in their development. This paper faces this criticism. Nickerson et al. have recently provided methodological guidance based on other taxonomic literature in other research fields. Future exploration of interaction taxonomies might compare the classification system outlined in this paper with those derived from more rigorous approaches.

6 Conclusions

This paper provides an initial thought based investigation towards a taxonomy of human-computer interaction that includes advanced (symbiotic) systems. The work was inspired through an EC funded project called CEEDs to research and develop a visual analytics based system that facilitates user creativity and discovery in massive datasets by exploiting measurable aspects of human perception and intention.

Through critical and creative thinking and stakeholder consultation, a range of variables were identified that influence what might be possible with new systems that seek to offer symbiotic and other types of human-computer interaction: primarily, content displayed (raw/tagged), types of user responses stored by the system (explicit/implicit), and real time influence (of explicit/implicit responses). Impact of variation in the number of concurrent users, and of more than one group of users was also considered.

It is possible that some types of so called symbiotic systems may not be perceived by users as symbiotic. People are variably attuned to the (conscious/unconscious) impacts they have on others (people/objects) in our day to day interactions with the world. However people as technology users are far less familiar with being exposed through technology to the influence of their implicit responses to the world (physical or virtual) around them. Understanding how to optimally harness this symbiosis for different types of interaction to facilitate creativity, discovery and understanding of complex data is no minor task. How do different levels of self-awareness of one's own implicit responses impact on the sense of this kind of symbiotic 'attunement'? What factors influence the extent to which the interactions derived from implicit user responses are perceived as natural and not jarred?

Attempts at symbiotic interactions that make use of implicit user responses may initially require practice and experience, like driving a car. Perhaps as we become more familiar with using these new symbiotic tools, we will learn new ways of making more integrated sense of our technology reflected intentions.

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