From human-computer interaction to cognitive infocommunications: a cognitive science perspective

Agoston Torok
Brain Imaging Centre, RCNS HAS, Hungary
Synetiq Ltd., Hungary
Cognitive Psychology Department, FEP ELTE, Hungary
torok.agoston@ttk.mta.hu

***Abstract*—In recent years virtual reality, augmented reality, wearables, and deep learning became more and more widely used. Thus emerged a new challenge for human-computer interface design: understanding the human user. In the current work, I describe four areas of understanding, which are human behavior, human limits, human needs and human cognition. These together form the basis of a new way of interaction between computers and us. A way where collaboration replaces commands; where respect of each other's limits is emphasized over limitless freedom; user interfaces become–dynamic and responsive instead of static and unaware; and self-explaining design instead of user guides. I will discuss how these factors are dependent on each other and work as an integrated whole to revolutionize interfaces. I'm presenting this work from a cognitive scientific point of view, which focuses on the human factor in information and communications technology and uses quantitative methods to analyze behavior, limits, needs, and cognition.**

Keywords—user interface; affordance; dynamic interface; cognitive infocommunications

I. Introduction

We live in a time of transition; in an exciting era in which the global spread of technological innovations – such as virtual reality (VR), augmented reality (AR), wearables, and machine learning - is transforming the traditional way of interaction with our surroundings. In this paper, we seek to summarize how this transition is changing human-computer interaction (HCI) and information and communications technology (ICT). Although several excellent reviews are already available on the topic [1]–[4], our novel approach is due to its primarily cognitive science viewpoint. This paper is divided into six parts. First, we explain the importance of this transition from a human-centered, rather than a technological perspective. Then, we identify four key pillars of the new human-computer interaction paradigm, which we describe one by one in four sections. The final part is a summary and discussion, where we outline the ways in which these four pillars function as an integrated system and define a new era of human-computer interaction leading to cognitive infocommunications.

II. A Brief History of ICT

It is tempting to present the history of ICT from the perspective of technological inventions. However, we should bear in mind that technological innovations must meet human demands in order to become significant disruptions. If this factor is taken into account, then the beginning of the 19th century gains a special kind of cultural importance. After all, this was the first time in human history, when - due to colonial expansion in North America – Western civilization, and on a smaller scale the families comprising it, got split into two. This increased the need for faster travel and led to new ways of distant communication.

A. Connecting

We can identify a *challenge of connecting* in the 19th century. To cope with this challenge the electric telegraph was invented in 1817 [5]. Although that model did not become the first commercially available telegraph, since it was based on static electricity, the inventor – Sir Francis Ronalds – judiciously described it as a tool for rapid global communication [5]. His vision became reality in 1837, when Cooke and Wheatstone patented their telegraph as the first commercial telecommunication tool [6].

The strong demand for true long-distance communication links appeared in the form of the first transatlantic telegraph cable, laid between 1854 and 1858 [7]. Although signal quality declined and even the cable was destroyed in a month, several attempts were made to replace it in the upcoming years, showing the significance of a communication link between the European and American continents.

While the telegraph was an important step in connecting people, it was not a natural way of communication as it required the understanding and rapid production of Morse codes. Thus, it is easy to see the next disruption in the 1876 patent of the first telephone system by Alexander Graham Bell [8]. This instrument was to the first one capable of transmitting human voice across large distances. It was not only faster than the telegraph, but, at the same time, more personal and more natural.

The last obstacle facing stable distant communication was the constraint of physical cables. This limitation was bridged by the invention of the wireless telegraph, better known as the radio in 1897 [9]. Marconi and Braun were awarded the Nobel Prize for this disruption in 1909.

B. *Accelerating*

In the 20th century, telecommunications became widely available. The two world wars, however increased the demand for accelerated information exchange. Technological disruptions of the past hundred years opened up new frontiers for mankind. Still, the state-of-the-art was limited by the technology of vacuum tubes. This barrier was overcome by the invention of the first point-contact transistor by Bardeen, Shockley, and Brattain at Bell Laboratories in 1947 [10]. Nine years later, they received the Nobel Prize, because this disruption enabled the miniaturization of several electronic devices. Today the transistor is an integral part of all the consumer electronic devices we use.

An important part of the development of info-communications was the birth of mass media. Two important areas were radio transmissions, starting as early as in the 1920s, and television broadcasting from 1929. In the early days of television, programs were live broadcasts, replay only became available in the 1950s. Nevertheless, the acceleration of information and communication technology was still limited by human factors: people had to find a wired phone to share information with each other, and information had to be acquired at specific locations (libraries) or at specific times (television programs).

The first barrier of location was broken down by the invention of the cellphone by Martin Cooper and colleagues in 1985 [11], [12]. The cellphone quickly become widely known, and in 10 years cell phone subscriptions reached 30 million, which grew to 110 million by 2000 in the US alone [13]. The second limitation of time was overcome in 1991, when the first website appeared (http://info.cern.ch/hypertext/WWW/TheProject.html) online and the world wide web (WWW) began to expand. In the beginning people accessed the WWW via dial-up connection using the telephone network. Soon it was obvious that a higher speed would be required and hence cable and satellite broadband connections became widespread.

III. Current challenges of ICT

As of today, there are almost 4.8 billion unique mobile subscribers in the world [14], and in the developed world people often spend more than seven hours a day looking at their computer or cellphone [15]. While the speed of internet connection is steadily increasing each year [16], so is the time we spend in front of ICT devices. Such long exposure to screens negatively affects our daily activities and our sleep pattern [15], [17], and there is increasing evidence for the negative effect of the magnitude of on-line information on our cognitive abilities [18], [19]. These are worrying developments and we believe that a new challenge has emerged for infocommunications. While ICT advances in the past 30 years caused incredible growth in the speed of communications [16], now we are facing a new limit for further development as current interfaces enable only suboptimal access to and search of on-line information. The interfaces of tomorrow must not only be marvels of engineering, but they must also reflect a better understanding of the human user to make daily life more effective and less stressful. Therefore, we believe *understanding* is the challenge of ICT today.

A. *Understanding*

Understanding is not only a challenge, but a radical paradigm shift. In the past, four key principles defined the interaction between humans and computers (see figure 1). First, worked primarily on a **command basis**. Regardless of whether it used a real command-line or a graphic user interface, the user defined what he/she wanted to do and the computer executed the task or returned an error message of some form. Second, **granting freedom** to the user played an important role in the design of both hardware and software. An example of this design principle is the first Android smartphone, HTC Dream, which had a slide-out QWERTY keyboard, a touch-screen, and physical buttons under the screen. Thus the user was free to use the device in a number of ways. Third, although the user was able to customize the **interface, it was otherwise static**. One reason for this was that early attempts of dynamic user interfaces (e.g. usage-based icon sorting on the iOS) did not become popular and worked ineffectively. Fourth, interfaces designed for complex tasks usually came with **instruction manuals**, and the user had to learn how to use the system. For instance, in the menu of the Chrome browser, the user had to learn what the *"settings"* menu was for, and which options were to be found under the "*tools"* menu. Although the difference between settings, preferences, tools, options, properties, and configuration can be defined, from a human-centered viewpoint any distinction between these categories is fuzzy, at least in everyday terms.

The challenge of understanding affects all four of the above mentioned principles. Below we describe four areas of understanding where human-computer interaction is changing to improve the effectiveness of ICT.

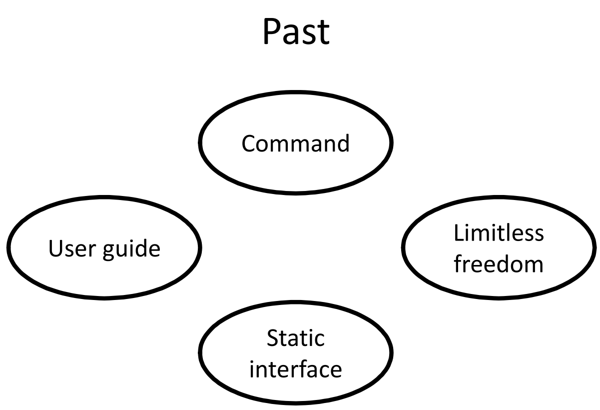

Fig. 1. Four key components of human-computer interaction in the past

B. Understanding human behavior

The reason why commands are still dominating interaction between humans and computers is that before the machine learning revolution (up until very recently) collaborative interaction was highly ineffective [20]. Collaboration requires the computer to understand the motivations of human actions (i.e. what the user *wants* when he/she *does* sg.). The PageRank algorithm used by Google [21] could be viewed as a successful attempt towards such a collaboration: it is based on the analysis of the links pointing to a page to calculate its importance in the information network. Because websites (including the links on the website to other websites) are created by humans, PageRank actually evaluates importance from a human-centered perspective. A prerequisite of this algorithm is the incredibly large number of websites, indexed and analyzed by Google. Big data also enables the analysis of human behavior in locomotion patterns and in texts [22], [23], and this opens up new ways of collaboration between humans and computers. By tracking our everyday activities computers can provide us with context-dependent information.

However, big data is often not yet available in several areas. For example, applications downloaded in the year 2015 from the various app stores (App Store, Google Play etc.) were often used for no more than one session, that is ~5 minutes [24]. In such a short time a vendor cannot collect much data which can help in the improvement of the user interface (UI) or functionality of the app. Nevertheless, such cases could still be subject to data mining based on knowledge discovery strategies, such as identifying frequent patterns of use [25]. While deep learning primarily relies on choosing the right architecture for making sense of large amounts of data, the success of knowledge discovery depends on predefined constraints and definitions of viable patterns [25], [26].

In summary, understanding human behavior is a difficult, data-intensive but necessary step to make human-computer interaction more efficient.

C. Understanding human limits

Tools can be designed in many ways, but the result will very rarely be actually usable for humans. The reason for this is that our cognition, and hence our representation of the world, is tied to our body and our senses [27]. In the past, interfaces were designed to give users more freedom to define their preferences. This was often not motivated by actual needs but instead by the lack of information about users' desires. Whereas we took the example of the first Android phone earlier to illustrate the notion of limitless freedom, the first iOS device in 2007 is an excellent example of a different approach. Compared to the almost limitless customizability of Android OS, iOS seemed rather limited: all applications were accessible from the home screen, and it was characterized by minimalist and consistent app interfaces, and dedicated hardware to create a seamless user experience. While it is often considered as Apple philosophy [28], it is a philosophy which is consistent with what psychology, cognitive science and neuroscience know about the limits of human cognition [29]–[32].

As virtual and augmented reality tools become popular, perhaps it is even more useful to discuss human limits in the design of nascent 3D UIs. Interactive virtual environments may in the future be a useful tool to expand our living-space. However, finding the ideal navigation in these spaces creates a great challenge for VR/AR designers. Extension means that we have to adapt the actual location change in real space to the virtual experience, thus virtual navigation is necessarily different from real one. To cover large distances there are two possible ways: flying and teleportation. It seems that flying (or in general gain of motion) works well in some cases [33], however it could become cumbersome if real, three dimensional motion is required and it is constricted by the limits of Euclidean geometry [34]. Indeed, research results show that the top-down axis granted by gravity is so important for our spatial representations that any distortion of this can lead to the underestimation of distance [35], [36] and disorientation [37]. Based on these results, it seems that flying is viable if motion is only done in 4 degrees of freedom (three translation axis and the yaw rotational axis). Transformation on the pitch and even more on the roll axis are problematic. On the other hand, studies show that teleportation (i.e. change of place without the feeling of motion) is readily processed by the brain [38], [39]. Teleportation is a favorable choice for long distances because the time required for changing place is constant (i.e. zero). An additional advantage of teleportation is that the lack of motion removes the constraints of Euclidean geometry. In the simplest case, we can easily understand that the shortest distance between two locations is *not* a straight line but a wormhole [40]. Furthermore, the whole routing system of wormholes can constitute an impossible physical space, for example a room which has multiple adjacent doors to other rooms of the same sizes. These would overlap in reality but in VR they can easily be fully explored.

Therefore, understanding human limits means considerations for design: sometimes in the form of limits but most often in ways to explore new frontiers.

D. Understanding human needs

Dynamic interface approaches often suffered from the lack of feedback in the past. Take, for example, usage-based icon sorting on smartphones. This works by monitoring the usage frequency and time of each app and sorting its icon in the launcher based on this information. It is often useful, because we – by definition – more often look for the frequently used apps. However, any rearrangement of the apps is risky: the user often taps to the expected place without even looking at the location. Even more unwanted is the outcome when, because of a rearrangement, the user is looking for the app all over the screen. Generally, icon sorting or any attempt towards making the user interface dynamic is an unsupervised learning challenge until we provide feedback of user experience that contains information other than the user uninstalling or abandoning the application.

Feedback from the user is costly: rating a product, writing a review, and usability tests take time and effort from the user's side. Luckily, there is potential user feedback during use: the user *looks* at the screen while searching and his or her *emotional state* changes when an action is successfully executed, when the search is ineffectual or even when it is stressful. Mining this data is so promising that there are a growing number of companies focusing on facial expression [41], eye tracking trajectories [42], and even brain or physiological signals [43] for usability testing and marketing. Some of these companies even released their software development kit (SDK), which can be built into other applications to utilize emotion recognition [44]. This provides an excellent opportunity to obtain real-time feedback to a dynamic interface.

Ongoing research on how computers (robots) can mimic and express emotions [45], [46] is also remarkable. A promising approach is crowdsourced data collection, which can help train robots to find appropriate emotional responses to a wide variety of situations [47].

Today, wearable biosignal recorders become increasingly popular and webcams/front-facing cameras are available to enable collection of data at an unprecedented scale. Therefore, by utilizing these tools human biosignal data mining is on the verge of entering the realm of true big data.

E. Understanding human cognition

Understanding human cognition is probably the most difficult of the four areas discussed here. Cognition is a unique way to comprehend the world around us. Therefore, understanding human cognition for a computer would ultimately mean the understanding of humans. Currently human-computer interaction works in a suboptimal way: we need to not only "explain" our will, but also to find a way to explain it to the computer. For example, if one wants to take a screenshot of a phone (a very easy operation) one can try several options, like pressing or long-pressing buttons, trying other button combinations, surfing the menu etc. None of these options are self-explaining, one only knows them from previous experience.

In the 1930s, Zipf described an empirical distribution of words in corpora, such that the relationship between the frequency of a word and its rank follows a power law function [48]. In communication this is believed to result from the actors' effort to balance the goal of communication (information transferring) and the cost of communication (words used) [49], [50]. Zipf's law has been observed in several fields, amongst others in computer command [51] and menu use [52]. Today the cost of communication in human-computer interaction way exceeds what would be ideal, which not only means more time to transfer the information, but likely also biases the user towards simplifying or even abandoning some information transfers. Finding ways to avoid this latter case is crucial to facilitate human engagement in meaningful communication with computers. Indeed, one of the most active areas of research in human-computer interaction is the design of effective collaborative protocols [53].

Facilitation of interaction starts at the first moment when the user meets the interface. Reading a user guide is not a communicative act, this is why self-explaining products are more popular. Self-explaining nature is described through the term *affordance* in psychology [54]. Affordance means that the object's appearance tells something about its function. For example, a door that has a long horizontal bar refers to the action of *pushing;* however, a door that has a vertical handle is likely to be *pulled* by the naïve user. Similarly, the turn-to-mute action on smartphones is self-explaining. Interestingly, while human-computer interaction has for a long time required unnatural hand-eye coordination of the mouse pointer; touchscreens and even more so virtual and augmented reality interfaces could be designed in a natural way. Here, instead of new artificial gestures, natural gestures could be used that are interpreted in a context dependent manner. A good example for this is the prototype of the Meta 2 augmented reality glasses, which uses the natural rotating gestures instead of an unnatural mouse-like one [55], [56].

In summary, understanding human cognition requires on the one hand the user to engage in meaningful communication and, on the other hand, the designer to set up the interface following the human perception of affordance.

IV. Conclusion

In the previous sections we discussed four areas of understanding that are necessary to master the current challenges of ICT. These were the understanding of human behavior, human limits, human needs, and human cognition. Putting emphasis on the human factor in design of interfaces and underlying systems is of vital importance. Based on these areas we represent the ideal way of future human-computer interaction in Figure 2.

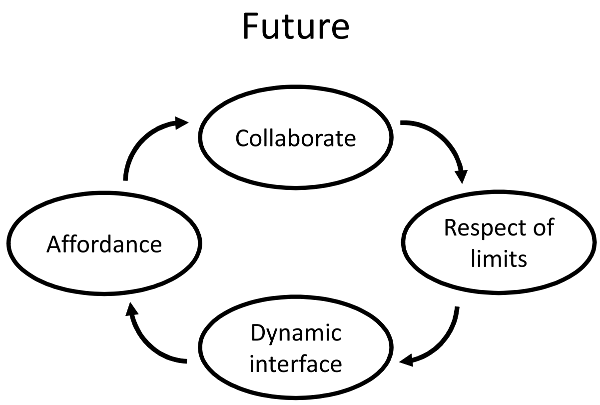

Fig. 2. Four key components of human-computer interaction in the future

While previously human-computer interaction was based on commands, recent developments in AR/VR and in deep learning has enabled interaction to proceed in a more collaborative way. Analysis of human behavior helps the computers to respond more effectively and in relevant ways to the human queries. Collaboration, in turn, only works when both sides are aware of each other's limits. This, on the one hand, means a contrary endeavor to the freedom-centered approach of the past. At the same time, it also permits a natural way of interaction with highly effective but so far neglected options (e.g. teleportation). In natural interaction, an action often gains meaning in a context-dependent manner. For example, pointing to an object could be selection, direction of attention, warning etc. Ideally an interface should differentiate between these by understanding human motivations. This understanding would lead to effective dynamic interfaces. The last component of the figure in the past was the user guide. Now it is clear that most general-purpose systems can be effectively used only if users can grasp their functions and how to operate them at a glance. The key concept is affordance in the design of human-computer interfaces.

The field of human-computer interaction design was already aware of these four factors [4], the contribution of the current work is to emphasize that these factors depend on each other. Thus, collaboration facilitates the understanding of human limits which, in turn, helps pave the way to dynamically adjusted interfaces. Efficient dynamic interfaces increase the affordance of the system, which further propagates collaboration. This novel approach revolutionizes human-computer interaction and hence the whole field of infocommunication. Therefore, cognitive infocommunication [57] emerges as the fundamental paradigm of the field.

Acknowledgment

The author would like to thank the support of the ELTE Multidisciplinary, the OTKA NK 101087 and the KTIA_AIK_12-1-2013-0037 grants, and additionally the support by a Young Researcher Fellowship from the Hungarian Academy of Sciences. The author is grateful for the comments of Zsolt Török, Linda Garami, Fanni Kling, Ádám Divák and Ádám Csapó that helped putting this work in an interdisciplinary perspective.

References

[1] R. Poli, D. Valeriani, and C. Cinel, “Collaborative brain-computer interface for aiding decision-making.,” *PLoS One*, vol. 9, no. 7, p. e102693, Jan. 2014.

[2] D. R. Gentner and J. Grudin, “Design Models for Computer-Human Interfaces,” *Computer (Long. Beach. Calif).*, vol. 29, no. 6, pp. 28–35, 1996.

[3] J. Grudin and D. A. Norman, “Language Evolution and Human-Computer Interaction,” in *Proceedings of the Thirteenth Annual Conference of the Cognitive Science Society*, 1991, pp. 611–616.

[4] B. Shneiderman, *Designing the user interface: strategies for effective human-computer interaction*. Pearson Education India, 2010.

[5] F. Ronalds, *Descriptions of an Electrical Telegraph: And of Some Other Electrical Apparatus*. R. Hunter, 1823.

[6] M. Trainer, “The role of patents in establishing global telecommunications,” *World Pat. Inf.*, vol. 29, no. 4, pp. 352–362, 2007.

[7] G. Cookson, “The TransAtlantic Telegraph Cable: Eighth wonder of the world,” *Hist. Today*, vol. 50, no. 3, p. 44, 2000.

[8] B. A. Graham, “Improvement in telegraphy.” Google Patents, Mar-1876.

[9] G. Marconi, “Improvements in Transmitting Electrical impulses and Signals, and in Apparatus therefor,” *Br. Pat.*, vol. 12, p. 39, 1897.

[10] R. Nelson, “The link between science and invention: The case of the transistor,” in *The rate and direction of inventive activity: Economic and social factors*, Princeton University Press, 1962, pp. 549–584.

[11] G. Goggin, *Cell phone culture: Mobile technology in everyday life*. Routledge, 2012.

[12] M. Cooper, R. W. Dronsuth, A. J. Leitich, J. C. N. Lynk, J. J. Mikulski, J. F. Mitchell, R. A. Richardson, and J. H. Sangster, “Radio telephone system.” Google Patents, Sep-1975.

[13] C.-T. W. Association, “CTIA semi-annual wireless industry survey.” Retrieved (2010, January) from http://www. ctia. org, 2010.

[14] G. Intelligence, “Definitive data and analysis for the mobile industry,” *GSMAintelligence. com*, 2016.

[15] J. K. Vallance, M. P. Buman, C. Stevinson, and B. M. Lynch, “Associations of overall sedentary time and screen time with sleep outcomes,” *Am. J. Health Behav.*, vol. 39, no. 1, pp. 62–67, 2015.

[16] M. K. Weldon, *The Future X Network: A Bell Labs Perspective*. Crc Press, 2016.

[17] A.-M. Chang, D. Aeschbach, J. F. Duffy, and C. A. Czeisler, “Evening use of light-emitting eReaders negatively affects sleep, circadian timing, and next-morning alertness,” *Proc. Natl. Acad. Sci.*, vol. 112, no. 4, pp. 1232–1237, 2015.

[18] H. J. Yoo, S. C. Cho, J. Ha, S. K. Yune, S. J. Kim, J. Hwang, A. Chung, Y. H. Sung, and I. K. Lyoo, “Attention deficit hyperactivity symptoms and internet addiction,” *Psychiatry Clin. Neurosci.*, vol. 58, no. 5, pp. 487–494, 2004.

[19] D. A. Christakis, “Internet addiction: a 21 st century epidemic?,” *BMC Med.*, vol. 8, no. 1, p. 1, 2010.

[20] Z. Ghahramani, “Probabilistic machine learning and artificial intelligence,” *Nature*, vol. 521, no. 7553, pp. 452–459, 2015.

[21] L. Page, S. Brin, R. Motwani, and T. Winograd, “The PageRank citation ranking: bringing order to the web.,” 1999.

[22] M. C. Gonzalez, C. A. Hidalgo, and A.-L. Barabasi, “Understanding individual human mobility patterns,” *Nature*, vol. 453, no. 7196, pp. 779–782, 2008.

[23] M. A. Russell, *Mining the Social Web: Data Mining Facebook, Twitter, LinkedIn, Google+, GitHub, and More*. “ O’Reilly Media, Inc.,” 2013.

[24] “statista–The statistics portal,” 2016. [Online]. Available: https://www.statista.com/statistics/202485/average-ipad-app-session-length-by-app-categories/. [Accessed: 29-Sep-2016].

[25] J. Han, M. Kamber, and J. Pei, *Data mining: concepts and techniques*. Elsevier, 2011.

[26] Y. LeCun, Y. Bengio, and G. Hinton, “Deep learning,” *Nature*, vol. 521, no. 7553, pp. 436–444, 2015.

[27] M. Wilson, “Six views of embodied cognition,” *Psychon. Bull. Rev.*, vol. 9, no. 4, pp. 625–636, 2002.

[28] T. O’Reilly, “Steve Jobs (1955-2011),” *Nature*, vol. 479, no. 7371, p. 42, 2011.

[29] G. A. Miller, “The magical number seven, plus or minus two: some limits on our capacity for processing information.,” *Psychol. Rev.*, vol. 63, no. 2, p. 81, 1956.

[30] A. Kiesel, M. Steinhauser, M. Wendt, M. Falkenstein, K. Jost, A. M. Philipp, and I. Koch, “Control and interference in task switching--a review.,” *Psychol. Bull.*, vol. 136, no. 5, pp. 849–74, Sep. 2010.

[31] C. Ho, R. Gray, and C. Spence, “To What Extent do the Findings of Laboratory-Based Spatial Attention Research Apply to the Real-World Setting of Driving,” *Human-Machine Systems, IEEE Transactions on*, vol. 44, no. 4. pp. 524–530, 2014.

[32] E. P. McCormick, C. D. Wickens, R. Banks, and M. Yeh, “Frame of Reference Effects on Scientific Visualization Subtasks,” *Hum. Factors J. Hum. Factors Ergon. Soc.*, vol. 40, no. 3, pp. 443–451, Sep. 1998.

[33] Re’flekt, “Audi AG,” 2015. [Online]. Available: https://www.re-flekt.com/portfolio-view/audi-vr-experience-en/. [Accessed: 29-Sep-2016].

[34] C. D. Wickens, J. G. Hollands, S. Banbury, and R. Parasuraman, *Engineering psychology & human performance*. Psychology Press, 2015.

[35] C. S. Di Cesare, F. R. Sarlegna, C. Bourdin, D. R. Mestre, and L. Bringoux, “Combined influence of visual scene and body tilt on arm pointing movements: gravity matters!,” *PLoS One*, vol. 9, no. 6, p. e99866, 2014.

[36] L. R. Harris and C. Mander, “Perceived distance depends on the orientation of both the body and the visual environment.,” *J. Vis.*, vol. 14, no. 12, p. 17, Jan. 2014.

[37] G. Clément, M.-J. Fraysse, and O. Deguine, “Mental representation of space in vestibular patients with otolithic or rotatory vertigo.,” *Neuroreport*, vol. 20, pp. 457–461, 2009.

[38] L. K. Vass, M. S. Copara, M. Seyal, K. Shahlaie, S. T. Farias, P. Y. Shen, and A. D. Ekstrom, “Oscillations Go the Distance: Low-

Frequency Human Hippocampal Oscillations Code Spatial Distance in the Absence of Sensory Cues during Teleportation," *Neuron*, pp. 1–7, Feb. 2016.
[39] Á. Török, "Spatial perception and cognition, insights from virtual reality experiments," Doctoral dissertation. ELTE University, 2016.
[40] B. Schnapp and W. Warren, "Wormholes in Virtual Reality: What spatial knowledge is learned for navigation?," *J. Vis.*, vol. 7, no. 9, p. 758, 2007.
[41] G. Szirtes, D. Szolgay, Á. Utasi, D. Takács, I. Petrás, and G. Fodor, "Facing reality: An industrial view on large scale use of facial expression analysis," in *Proceedings of the 2013 on Emotion recognition in the wild challenge and workshop*, 2013, pp. 1–8.
[42] R. de O. J. dos Santos, J. H. C. de Oliveira, J. B. Rocha, and J. de M. E. Giraldi, "Eye Tracking in Neuromarketing: A Research Agenda for Marketing Studies," *Int. J. Psychol. Stud.*, vol. 7, no. 1, p. 32, 2015.
[43] T. Nagy, D. Tellez, Á. Divák, E. Lógó, M. Köles, and B. Hámornik, "Predicting arousal with machine learning of EEG signals," in *Cognitive Infocommunications (CogInfoCom), 2014 5th IEEE Conference on*, 2014, pp. 137–140.
[44] D. McDuff, A. Mahmoud, M. Mavadati, M. Amr, J. Turcot, and R. el Kaliouby, "AFFDEX SDK: A Cross-Platform Real-Time Multi-Face Expression Recognition Toolkit," in *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, 2016, pp. 3723–3726.
[45] C. Breazeal, "Emotion and sociable humanoid robots," *Int. J. Human-Computer Stud.*, vol. 59, pp. 119–155, 2003.
[46] B. Cynthia, B. Daphna, G. Jesse, G. David, and B. Bruce, "Learning From and About Others : Towards Using Imitation to Bootstrap the Social Understanding of Others by Robots," *Artif. Life*, vol. 11, pp. 1–32, 2005.
[47] C. Breazeal, N. DePalma, J. Orkin, S. Chernova, and M. Jung, "Crowdsourcing human-robot interaction: New methods and system evaluation in a public en-vironment," *J. Human-Robot Interact.*, vol. 2, no. 1, pp. 82–111, 2013.
[48] G. K. Zipf, "The psycho-biology of language.," 1935.
[49] R. F. i Cancho and R. V Solé, "Least effort and the origins of scaling in human language," *Proc. Natl. Acad. Sci.*, vol. 100, no. 3, pp. 788–791, 2003.
[50] R. F. i Cancho, "The variation of Zipf's law in human language," *Eur. Phys. J. B-Condensed Matter Complex Syst.*, vol. 44, no. 2, pp. 249–257, 2005.
[51] S. R. Ellis and R. J. Hitchcock, "The emergence of Zipf's law: Spontaneous encoding optimization by users of a command language," *IEEE Trans. Syst. Man. Cybern.*, vol. 16, no. 3, pp. 423–427, 1986.
[52] A. Cockburn, C. Gutwin, and S. Greenberg, "A predictive model of menu performance," in *Proceedings of the SIGCHI conference on Human factors in computing systems*, 2007, pp. 627–636.
[53] E. Kamar, Y. K. Gal, and B. J. Grosz, "Modeling information exchange opportunities for effective human–computer teamwork," *Artif. Intell.*, vol. 195, pp. 528–550, 2013.
[54] J. J. Gibson, *The ecological approach to visual perception: classic edition*. Psychology Press, 1979.
[55] M. Gribetz, A. Ahuja, Z. Zhong, M. Hasek, and B. Sanders, "WIDE FIELD OF VIEW HEAD MOUNTED DISPLAY APPARATUSES, METHODS AND SYSTEMS." US Patent 20,160,139,413, 19-May-2016.
[56] M. Gribetz and W. S. G. Mann, "Extramissive spatial imaging digital eye glass apparatuses, methods and systems for virtual or augmediated vision, manipulation, creation, or interaction with objects, materials, or other entities." Google Patents, 03-Jan-2014.
[57] P. Baranyi, Á. Csapó, and G. Sallai, *Cognitive Infocommunications (CogInfoCom)*. Springer, 2015.