M.I.T Media Laboratory Perceptual Computing Section Technical Report No. 469
Appeared: Proceedings of the IEEE

Human-Computer Coupling

Rosalind W. Picard
MIT Media Laboratory; 20 Ames Street; Cambridge, MA 02139
Phone: 617-253-0611; Fax: 617-253-8874
picard@media.mit.edu; http://www.media.mit.edu/~picard

1 Introduction

In "Man-machine coupling," Page's vision is one of virtually unlimited capability for machines, with the expectation that coupling man and machine would become so complete, so perfect, that it would ultimately allow full transfer of our human thoughts and expressions, not only to machines, but through them, from human to human. His vision is not one of simply extending man's reach or strength through machines, or of transferring human control and reach to distant new sites, but one of direct transference of thoughts and feelings. There would be no terra incognita for machines: no aspect of the human mind would be impervious to their scrutiny and understanding. Machines could provide even the elusive links that are needed to improve human mutual understanding.

No doubt encouraged to speculate and dream for his article, Page cannot be chided for chimerical proclamations any more than for his use of the parlance "man-machine coupling," instead of today's most likely substitute: "human-computer interaction." Today's language will continue to evolve, especially as the notion of "computer" shifts from one of boxes on desk tops and lap tops, to chips and sensors in our shoes, jewelry, eyeglasses, furniture, and everything manufactured, to conductive threads in our jackets, implanted devices in our bodies, and even to ingestible and inhalable computational forms. Today, a person can swallow a pill that contains a sensor and transmitter for sending core body temperature to an off-body receiver; this technology, in fact, originated in the sixties. Computational devices in forms such as pills and sneakers bear even less resemblance to today's prototypical "Intel inside" computers than do the mechanical machines, motors, and room-filling "electronic brains" of Page's day.

Page's choice of "coupling" instead of "interaction" is a provocative one for us to consider. His descriptions do not include overtones of sexual union, despite that these connotations might be inevitable in today's world where cyber-sex makes headlines. Neither is Page's focus aligned with today's battles over the need for GUI's or more tangible interfaces, or on whether such interfaces should be proactive in their actions, or await direct manipulation by people. Instead, Page's focus is on the communication that happens between man and machine, especially from man to machine. In particular, he focuses on the desire for effortless and direct communication of concepts of the human mind, specifically those that can be hard to express in language and pictures, those that include feelings.

2 From servos to stockings

The way to the secret garden in Page's day was control theory, with its feedback mechanisms and servo systems. We see evidence of this premise in his lines: "Electrical circuits and radios can close control loops extending around the world and into space," and "A servo system could easily be made to operate the stimulating means by controlled amplified feedback ...with independent control of feedback phase and gain it should be possible to study in great detail the operation of the brain in some particular activity." Based on these premises, Page speculates on just how the evolution toward transferring ideas from mind to machine might occur.

Page's idea starts with the acknowledgment that certain activities of the brain result in electrical potentials that can be measured on the surface of the scalp, without pain or discomfort to that person. The technique today would likely involve an electroencephalograph (EEG), which was also standard by the early 1950's, although Page doesn't refer to an EEG by name. Today there exist easy to use 128-electrode array scalp EEG's, that a researcher can quickly seat on a subjects's head. There also exist a host of new brain imaging techniques, such as functional magnetic resonance imaging, that can provide even more information about the activities of the brain. Nonetheless, there are many problems both with the limited usability of these devices and with the nature of the brain's own dynamic states that prevent current brain imaging techniques from revealing precisely what a person is thinking. Nor does direct thought-recognition appear achievable within the next decade.

Page's description suggests the possibility of sensing not just brain signals, but many other bodily signals, such as galvanic skin conductivity, which was also in general use at the time of writing his essay. Skin conductivity is one of the best known measures of what psychologists call arousal level, which tends to increase with the onset of an event that captures your attention, such as a loud startling noise. Additionally he mentions bodily movement, pulse, respiration, temperature, blood pressure, and blood composition, all of which can be measured now by off-the-shelf medical devices, most of which are wearable and can be used in an ambulatory way, as the wearer goes about routine activities. These devices allow a computer to get to know a person's physiological changes, including those changes that may be indicative of the person's emotions.

The emphasis on servo systems for stimulating brain activities may have been inspired, in part, by other work around the time of Page's article involving electrical stimulation of neural circuits. In particular, there was work at

Massachusetts General Hospital around that time involving the simulation of neural circuits in cadavers. The idea was to put electrodes on a nerve to determine the computer-generated waveform that would control movement of each limb. This was the beginning of efforts to couple machines into the human body for controlling artificial limbs. These experiments continue today in many places, but now occur with living people and a variety of prostheses. Page evidently believed that it was a matter of time before human thoughts could control such devices, given coupling with an intermediate machine.

Active research exists today in coupling electronics with the human body and mind. Well-established efforts, targeted primarily at assisting the physically disabled, aim to give people the ability to think "lift my prosthetic arm," and have that arm lift in a reliable and controllable way; or to think, "walk," and have their legs do the right thing. Computational circuitry has indeed migrated into the human body; there are cochlear implants, retinal implants, artificial organs, pacemakers, not to mention numerous externally-worn devices for augmenting human abilities that might not be far off from being moved inside the body. Control theory has influenced the design of many of these systems, but in many more cases, it has been only a small part of the solution.

When Manfred Clynes coined the word "Cyborg" for "cybernetic organism" in 1960 [1], he had in mind just these kinds of scenarios where technology couples with and assists a person without placing burdensome demands on the person. His example of a cyborg was a person who uses technology such as a spacesuit to augment his or her human abilities in a natural and effortless way, for example, by being able to breathe in outer space. The person doesn't have to consciously control the space suit, but can acclimate to it, forget about it, and breathe and move about naturally.

Today we find increasing examples of "cyborgian" augmentation emerging for everyday use by non physically disabled people, in the form of wearable computers. Athletes wear heart-rate monitors that download data to their watches and off-body to their PC's for analysis. Wearable PC's exist that can serve as "memory augmentation devices," searching your online data for ideas similar to the one you just recorded. A couple decades ago, Steve Mann developed his own wearable computational systems for augmenting his ability to control his photography gear and to see the world through his camera's lens. His 1990's "personal imaging systems" now provide on-body capabilities for capturing and transmitting voice, image, and video data, and can be configured to augment the way he literally sees the world, among other capabilities [2].

Numerous wearable systems have been built to augment human abilities in a "cyborgian" sense. Last year marked the meeting of the First International Symposium on Wearable Computers sponsored by the IEEE. The evolution of wearable machines offers a paradigm shift from machines as servos, electronic circuits, and PC boxes to machines as washable clothing made of conductive threads, stockings and insoles that sense foot perspiration, temperature, circulation, and location, and other wearable devices that make booting up your computer less like flipping a switch and more like slipping on a favorite pair of shoes.

3 Affective communication

In 1962, there was nothing very responsive about computer interaction compared to today; most processing was "batch" and permitted the programmers to enjoy some time of repast and mental debugging before a processed response blipped from the machine. Computers were sessile, and unable to accompany people or to learn much about them outside the large rooms in which they interacted. Human-computer interaction was far from emulating natural human-human interaction. Hence, it was interesting that Page jumped to the latter for predicting the future of the former.

Page was prescient in recognizing the importance of the content of natural human-human communication when considering man-machine coupling. Today, based on scores of experiments, researchers have argued that human-computer interaction is inherently natural and social, i.e., it follows the basic rules of human-human interaction [3]. Today, one might argue that giving computers human-like interaction abilities can be motivated for the practical reason of making communicating with them easier for us people, as opposed to being motivated by narcissism or perhaps even a desire to imitate God in making machines in our image.

Page astutely writes of the *affective* aspects of human communication—the gestures, respiration, skin color, expressions of the eyes, and more—that communicate human feelings as an important part of the message. For example, sometimes *what* was said, is not as important as *how* it was said. Despite Page's acknowledgment of the importance of affective communication, most efforts to give computers communication abilities have focused only on the equivalent of "what" has been said, not on "how." The affective signals have been treated by engineers largely as noise.

Affective aspects of communication are now recognized to be a crucial part of human intelligence [4] [5], and, together with several other emotional skills, have been argued to be more important for success in life than traditional mathematical and verbal forms of intelligence [6]. These so-called skills of "emotional intelligence" are now starting to be given to computers [7]. One can expect within the next decade to see computers that can recognize certain emotional expressions of a user that they interact regularly with, and to respond in a way that intelligently acknowledges such expressions, at least in limited contexts.

4 Two present-day examples

In the MIT Media Lab, we have several projects underway to give computers the ability to recognize natural forms of human communication, especially to interpret signals such as facial expression, vocal intonation, muscular movement, gesture, respiration, and even autonomic nervous system signals. This effort is concurrent with the development of wearable computers, leading to devices that illustrate a merging of the ideas above. For example, we are devloping "affective wearables," wearable systems equipped with sensors and tools that enable recognition of a wearer's affective patterns. These systems couple human signals with online analysis in an effort to better understand the wearer, and to provide her with useful personalized service.

Consider the "StartleCam," a research prototype developed at the MIT Media Lab by Jennifer Healey and colleagues. This consists of a wearable camera in the form of a small pendant or tie tack, a wearable PC, a galvanic skin conductivity sensor, and special pattern recognition software that has been trained to recognize patterns in the wearer's skin conductivity indicative of a high-arousal situation. The camera always saves video into a circular buffer, so that you never need to worry about not having had the camera on when you saw something you wanted a shot of. However, it is impractical to save all the data, as this would lead to tremendous information overload and waste of your time, not to mention inordinate storage requirements. To get around this problem, the system saves data for the wearer in (currently) two cases: (1) when the wearer designates; and (2) when an event, such as a startle, gets the wearer's attention. In the latter case, especially when an event is of great interest to the wearer, she may forget to direct the camera to save the data until it is too late. The camera, by being coupled to the wearer, can learn to recognize such situations, and thereby better assist the person. Of course the system also offers hands-free video, which can be useful when filming while skiing down a mountain, playing with children, or otherwise engaged in activities where you want to record an event but don't want to be troubled by having to manipulate the technology.

We can expect that Page would have suggested that systems like a StartleCam should operate when you merely think "record this video." That would be nice in some cases, but in our experience, you sometimes think too late to record. Systems like the StartleCam go a step further than what Page suggested, learning patterns that can be used to try to predict your preferences and actions. They are like a companion brain that runs even when your brain is busy doing something else. Our goal is to make them more like an assistant that learns your preferences and tries to anticipate how best to help you, without always requiring your direct control.

Another example of a wearable device for communicating emotion not only from human to computer, but also through computers to possibly distant humans, is a pair of "expression glasses." Under development at the MIT Media Lab by Jocelyn Riseberg and colleagues, these eyeglasses contain a small skin-surface sensor that senses changes in the facial muscles during expressions such as confusion or interest. When a person wearing the glasses furrows his brow in confusion, the signal is relayed to the computer. Suppose this signal occurs while the computer is interacting with the person in a learning situation. In that case, the computer might respond to the person's confusion by offering the user an alternate explanation of what is going on.

The computer can alternatively relay the human expressive signal from the glasses over great distances, acting as a smart communications channel. It could send responses from students around the world to a lecturer in a remote location. The lecturer might not be able to see all the students, but might still be able to see a kind of "barometer" allowing assessment of their confusion, interest, or other important feedback that the students wanted to communicate to enable the lecturer to better adjust the pace and presentation of the lecture. The information can even be relayed in an anonymous fashion, if that is desirable. This situation is just one example of where machines can act as "interpreter" of human communication signals, as Page hints will become possible. In this situation the glasses aid in communication of a natural mode of communication—furrowing one's brow—as opposed to a mode people cannot read directly from one another, such as brain waves.

5 Foreseeing problems

Glasses, as opposed to other methods for sensing such information, provide a familiar and comfortable paradigm when it comes to a person feeling "in control" of the sensing technology: it is easy to take one's glasses off, or to physically disconnect the sensor on the glasses. In this sense, wearables such as the eyeglasses may be a better coupling solution than non-contact sensors placed in the walls of a room, or cameras that gather data from a distance. Privacy and user-control issues are a primary concern of these new technologies, especially where affective information is to be communicated. Page skips this issue, but it is sure to be a crucial one as this kind of technology becomes increasingly available.

Perhaps the biggest understatement in Page's description of the man-machine coupling roadblock is in his remark, "Once sufficient transfer of information from man to electrical circuit is achieved, machines can be built which will "understand" that information with speed and accuracy possible only with machines." Speed and accuracy are not the issues when it comes to truly understanding the terabytes of data that can be transferred from people. The challenges faced today are: first, our own understanding of the real information in this data, and second, endowing computers with this knowledge. I suppose it is also possible that computers might acquire certain aspects of this knowledge before we do; in that case, the order of these flips. For at least the next decade, however, we will likely remain busy acquiring more human understanding about how we best communicate, and trying to help computers learn what we have learned.

Page ends on a dubious note about a future with direct human-to-human coupling where presumably we would be connected in a way that we could know each others thoughts, feelings, and movements through direct access. The ideal sounds nice—perfect, unhindered communication. The reality, however, is the kind of nightmare of which tragedies are made. Anyone who has ever tried to share all their thoughts or feelings with someone has a strong respect for the fact that our thoughts remain private, able to be filtered by our will before we share them with others. In the privacy of the human mind we can choose what to speak and what to withhold.

Suppose that a husband, discussing a possible divorce with his wife, has a passing thought, "I wonder if I ever loved her?" Despite all the existing evidence that once he really did love her, his wife may not be able to get his words out of her mind, and may become so upset about this that she does not hear him counter the statement with his next round of passing thoughts. The fact is that the truth within ourselves sometimes comes to us only after thinking about many possibilities that are untrue. As long as our brains take paths through things that might be best unspoken, we should value the privacy our enclosed mind offers. Freedom to contemplate whatever we wish, free from the scrutiny of machines and fellow man is a privilege that we should place great value upon.

Direct coupling of mental thought could lead to all kinds of very serious misunderstandings, not to mention mental overload, distraction, and work for actual "thought police." Given the current limitations of the human mind, we should question seriously the potential use of the technology Page proposes for regular human-human interaction. It is one thing to build machines that help us understand how the mind works, and that assist us in physical, psychological, and biological functions as Page predicts, and as we see happening. There are indeed successful expert systems that advise physicians about medical diagnoses and treatments, for example. However, it is another thing entirely to turn our minds over to such machines. One cannot help but wonder how such machines would otherwise influence our human physical, psychological, and biological state.

Several of these issues boil down to an ability to make intelligent decisions about information. Here, too, researchers have largely left emotion out of the picture, but this will likely change over the coming decade. The focus in the last several decades in the pursuit of artificial intelligence has been on logical rule-based reasoning, which tends to be brittle and limited to well-defined problems. This focus can be expected to shift given new neurological findings about the critical role of human emotion for even rational decision making. Such findings have shown that people who essentially do not have enough emotions (because of brain damage) do not behave more rationally or intelligently, but actually are severely impaired when it comes to ordinary day-to-day decision making [8]. In other words, too little, as well as too much emotion is detrimental to rational functioning. A balance is needed, and this balance has been missing from machines. The importance of this balance in human decision making suggests that the machines that Page says will "make decisions" will need to have certain emotional abilities, or their mechanistic equivalents.

6 Conclusions

"Man-machine coupling," effecting the transfer of a human's thoughts, movements, and feelings to a computer, remains a roadblock today. Alas, the 1960's reigning belief in the path of control theory for directly coupling us to machines and removing the need for "teams of programmers" has not provided the solution, although control theory has been of great use in the development of new technologies. Instead, teams of programmers are still necessary for enabling machines to interpret the signals that carry human communication. Such teams appear to be growing, not shrinking, in the coming decade.

Current researchers are embracing the importance of including more than purely logical expressions of thought in human-machine interaction. Software agents and other computational devices are being given new abilities to recognize not only what people do, but also what feelings they express. New designs for sensing physiological signals have been constructed in jewelry, shoes, eyeglasses, and other wearable forms, facilitating a more natural and comfortable form of coupling between the human and computer. Computers have entered the physical, psychological, and biological realms Page envisioned and may even be given human-like mechanisms of emotion for facilitating better decision-making. The new capabilities of such machines also imply new responsibilities for their designers and new concerns for their users, especially regarding privacy and user control.

The last few decades have brought a shift in emphasis regarding human-machine coupling. Today one does not hear much about efforts to develop direct mind transfer of human thoughts, feelings, and movements to machines. Today's more imminent ideal for 2012 might be stated like this: to enable computers to sense and interpret the natural forms of human communication and to learn, in an ongoing way, to respond intelligently to this information.

The view Page espoused gave computers access to all that we humanly are; the new view implies a respectful distance, giving computers the same access to our minds and hearts as we might allow certain people, but not making them into a God that could know *everything* we think, feel, and do.

Acknowledgments

I am grateful to Howard Hermann, M.D., for discussing with me his insights into the technology of the late 1950's and early 1960's, and to Len Picard for his helpful comments on this article.

References

[1] M. Clynes and N. S. Kline, "Cyborgs and space," *Astronautics*, vol. 14, pp. 26–27 and 74–76, Sept. 1960.

[2] S. Mann, "Wearable computing: A first step toward personal imaging," *Computer*, pp. 25–31, February 1997.

[3] B. Reeves and C. Nass, *The Media Equation*. Cambridge University Press; Center for the Study of Language and Information, 1996.

[4] H. Gardner, *Frames of Mind*. New York: BasicBooks, 1983.

[5] P. Salovey and J. D. Mayer, "Emotional intelligence," *Imagination, Cognition and Personality*, vol. 9, no. 3, pp. 185–211, 1990.

[6] D. Goleman, *Emotional Intelligence*. New York: Bantam Books, 1995.

[7] R. W. Picard, *Affective Computing*. Cambridge, MA: The MIT Press, 1997.

[8] A. R. Damasio, *Descartes' Error: Emotion, Reason, and the Human Brain*. New York, NY: Gosset/Putnam Press, 1994.