Chapter 1

Human-technology Integration

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Human-technology integration is the replacement of human parts and extension of human capabilities with engineered devices and substrates. Its result is hybrid biological-artificial systems. We discuss here four categories of products furthering human-technology integration: wearable computers, pervasive computing environments, engineered tissues and organs, and prosthetics. We introduce examples of currently realized systems from each category. We then formulate two different predictions regarding the observational consequence of the replacement of every biologically-based human part with an engineered substitute.

1.1 Introduction

At least since Turing[1], the *intelligence* of machines has been benchmarked in terms of performance compared to a human's on some set of tasks. The usual way to engineer systems that are intelligent in this sense, i.e., with performance isomorphic to a human's on some set of tasks, is to engineer a system *de novo* able to approximate some aspect of human behavior, and then iteratively improve the system in order to generate progressively more human-like performance. In this paper we discuss an alternative means toward engineered systems with human-like performance: *human-technology integration*. The human-technology integration approach begins with existing humans and proceeds by augmenting or replacing "natural" parts with engineered devices and substrates to result in hybrid biological-artificial systems that are more and more artificial.

The means of human-technology integration are devices that allow the extension of human senses and capacity to act into the environment, such as (wearable) computing devices and pervasive computing environments, as well as products that substitute or modify aspects of human's existing organic structure, e.g., prosthetics and engineered tissues and organs. Such means will be discussed in brief.

Human-technology integration currently results in hybrid biological-artificial systems; continued development will conceivably allow the creation of entirely artificial systems by its means. The possible observational consequences of replacement of each and every human part with an artificial substitute are the subject of the last section of this paper. We formulate a *replacement experiment* in which a human observer transfers their embodiment completely to engineered devices or substrates, and present two different predictions regarding the results. Interestingly, the replacement experiment presents an observational means to confirm the possibility of an aware artificial system.

1.2 Wearable computers

Advances in computer technology have brought not just faster and more powerful machines: they have brought the human user closer to computational power, where *closer* means having the ability to access computational power in a less conditional sense. The advent of the personal computer and the laptop and palmtop computers removed barriers separating the user from access to computer power, and the wearable computer, or wearable, works to further diminish barriers that remain.

Wearables package computing power in a form that goes wherever the user does, embedded in clothing or carried on the head or body. Wearable developer Steve Mann prompts

> Let's imagine a new approach to computing in which the apparatus is always ready for use because it is worn like clothing. The computer screen, which also serves as a viewfinder, is visible at all times and performs multimodal computing (text and images). [2]

Wearables effectively allow the user to extend their ability to compute into their environment regardless of their primary task, allowing access to computational power in settings in which the use of a traditional portable computer is cumbersome or impossible. For example, wearables may assist soldiers in combat situations in which the use of traditional portable computing devices is not feasible. The 'Objective Force Warrior" (OFW) project of the United States Army currently explores the "synergistic result" of combining soldiers with wearables. The "overall warrior system" in development includes a helmet with 180 degree integrated display with voice control command software, video/data links to networked sensors, multi-spectral vision, thermal management and temperature control, biometric sensors, hemorrhage control, virtual reality/3D visualization software, tactics, techniques and procedures (TTP) recall, and integrated mission rehearsal capability [3].

The *always ready* mode of wearables allows their users to assimilate information processing tasks more seamlessly into their activities, making them of considerable interest to businesses. For example, the Mobile Assistant wearable computer from Xybernaut Corp. has been used by the service personnel of the telecommunications carrier Bell Canada International Inc. since 2000 to speed data processing tasks in the field, allowing an estimated time savings of 50 minutes per day per worker. The pilot version of the Mobile Assistant used by Bell was a head-mounted display (HMD), which was soon replaced with flat-panel 8-in. display that allows pen input on the screen or with an electronic keyboard attached to a processor embedded in a vest, belt or knapsack[4]. Because such devices ease human-computer interaction in such a way as to allow businesses to operate more efficiently, their use is rapidly spreading.

1.3 Pervasive computing environments

Pervasive computing environments attain to a seamless continuum between the computing environment and the physical environment, and may be compared to a nervous system for the environment being sensed [5]. Human-technology integration is facilitated by by allowing human users an unprecedented opportunity to collect information from (sense) and act on their environments.

Sensors and sensor networks are a component of pervasive computing environments that facilitate an extension their users an extended ability to monitor their surroundings. A common and relatively mature such technology is the closed-circuit television (CCTV) camera, which is used by individuals and institutions worldwide to extend a "watchful eye" into the environment. The British government, for instance, has installed 1.5 million CCTV cameras in public and semi-public places. Cameras currently line nearly every road and public square in the country, manned by human operators that decide whom to survey in detail and for how long, allowing for increasingly ubiquitous presence of governmental agents.

Another pervasive computing technology in wide use to increase user's capacity to survey the physical environment are radio frequency identification (RFID) sensors, which turn the objects they are affixed to into network nodes that uplink IDs and data to databases. The tags are dormant until activated by a RFID reader, which stimulates the RDID to broadcast information. They are currently used by businesses (e.g. Procter and Gamble, Gillette and Wal-mart) to manage inventory, several U.S. state governments to track cars in order to levy tolls (via the EZPass system), and a wide range of institutions to track the activity of employees via tags embedded in ID badges. Applications for personal use are in development.

1.4 Engineered tissues and organs

Engineered tissues and artificial organs act to restore function to human patients in the case of tissue or organ damage due to to injury, age or disease. Unlike the technologies of human-technology integration discussed thus far, engineered tissues and organs may actually replace (as opposed to merely augment) existing human parts.

A strong impetus for the development of artificial organs exists because of the donor shortage–in excess of 70,000 individuals in the U.S. alone wait for organ transplantation each year, but fewer than 11,000 donors (cadaveric and living) are available [6]. Some of this donor shortage is currently remedied via use of artificial organs. The artificial heart is the oldest example of a functional artificial organ. In 1957 Willem Kolff and his associates successfully implanted the first artificial heart in an animal. In 1969 Denton A. Cooley, founder and became the first heart surgeon to implant an artificial heart in a human patient. The first fully self-contained artificial heart was successfully implanted in 2001. The device, manufactured the AbioCor Corporation, is currently in U.S. Food and Drug Administration (FDA)-approved clinical trials. Other artificial organs, such as livers and kidneys, have also been in long development, and are meeting increasing success in clinical applications.

Artificial tissues differ from artificial organs in that they are typically comprised of biologically-derived materials. Tissue engineering itself is defined as the application of principles and methods of engineering and life sciences toward the development of biological substitutes to restore, maintain or improve tissue function [7]. The engineered tissue most common use today is skin. Creation of replacement skin typically involves *in vitro* seeding and attachment of human cells to a biodegradable polymer or collagen scaffold, which is then bathed with growth factors, causing proliferation, migration and differentiation of the seed cells. Upon implantation, the scaffold is gradually reabsorbed into the body. Skin created in this way is presently used as a replacement for the damaged skin of burn victims and the sufferers of diabetic ulcers, among others. Research in progress in the creation of other artificial tissues, including blood vessels, connective tissues, and blood itself promises to help meet the health heath needs of many more.

1.5 Prosthetics

A prosthetic is generally defined to be a corrective consisting of a replacement for a part of the body. In general, prosthetics can "restore lost mobility to individuals if (i) they can express cognitive control over relevant motor functions somewhere in their residual anatomy and (ii) a device can pick up and decipher that cognition[8]."

Myoelectric limbs, for instance, operate by sensing electric signals generated by the muscles of the remnant limb. Sensors embedded in tight-fitting rubber prosthetics pressed against the remnant limb pick up electric electromyographic

(EMG) signals, which are then amplified and sent to microprocessors that operate motors in the joints of the artificial limb. The devices help amputees worldwide toward functional replacement of their upper-limbs.

Even patients with complete paralysis, or locked-in syndrome, may use prosthetics to direct activity. In locked-in patients, the series of electrical impulses that pass from brain cells along nerves to trigger the release of chemical messages that result in movement of the muscles is blocked, leaving the brain fully conscious but unable to control the body. Brain computer interfaces (BCI's) allow such patients to direct external devices such as computer mice or robotic arms using their thoughts alone.

BCI's rely on the ability of individuals to voluntarily and reliably produce changes in their electroencephalographic (EEG) activity. Since 1997 BCI's have been implanted in locked-in patients who learn to use their brain waves to "will" a cursor to move and then stop on a specific point on a computer screen. The screen is typically made to contain a list of options or characters from which the patient may choose in order to construct messages. The technology has been extended to allow control of robotic limbs[9, 10].

Since the successful development of proof-of-concept devices, interest in the development of BCI's has grown. In the U.S., The National Institutes of Health awarded $3.3 million in late 2002 to a partnership headed by the Wadsworth group to help match BCI software to patients, and DARPA awarded a Duke University research team $26 million in 2003 to improve its implanted BCI technique. A DARPA spokesperson reports that the agency is interested applications such as enabling "soldiers to push buttons with their brains, giving them speedier control of submarines and aircraft and enabling them to more adeptly manipulate robotic arms that move munitions[11]."

Artificial eyes, or visual prosthesis, are another promising prosthetic device that seek to provide functional visual perception to a individuals blinded by disease or trauma. The devices are based on neuronal electrical stimulation at different locations along the visual pathway (i.e., cortical, optic nerve, epiretinal, subretinal)[12]. Several researchers have reported successful restoration of some part of lost vision via implantation of artificial retinas, e.g., [13, 14]. The ongoing Artificial Retina Project will standardize and extend the current state-of-the-art in artificial stimulation of the retinal nerves with three rounds of clinical trials of progressively more sophisticated devices. Five U.S. national laboratories, three universities, and the private sector are collaborating on the project, which will receive $9 million in funding from the U.S. Department of Energy's Office of Science over three years[15].

1.6 The future of human-technology integration

The categories of technologies described in previous sections, among others, allow for the creation of hybrid biological-artificial intelligent systems. These hybrid systems offer their human components either i) an extension of the capability to collect, interpret and act on environment information, or ii) the maintenance of "normal" or healthy functionality of damaged, diseased or aging parts. Since there is considerable demand for both i) and ii), there exists a strong impetus to further the means of human-technology integration.

As this impetus enables humans to replace or extend more and more of their components with artificial devices and substrates, it will become possible for the resulting intelligent biological-artificial systems to become increasingly artificial. At some future point it is conceivable that a human will be able to replace *all* "natural" parts with engineered components, to result in a completely artificial system with human-like performance on some set of tasks.

Whereas there is general consensus that human parts and even the human whole may be replaced in principle by a *functionally* isomorphic artificial system, there remains debate regarding whether artificial systems can be made to be aware (i.e., conscious, feeling, with qualia, etc.). This debate is philosophic since observable qualities by which to distinguish matter that merely *acts* as though it has awareness from matter that actually *has* awareness are not known to exist. On the debate regarding whether it is possible for an artificial (i.e., non-biological) system to be aware, Marvin Minsky comments

> Many thinkers firmly maintain that machines will never have thoughts like ours, because no matter how we build them, they'll always lack some vital ingredient. They call this essence by various names–like sentience, consciousness, spirit, or soul. Philosophers write entire books to prove that, because of this deficiency, machines can never feel or understand the sorts of things that people do. [16]

From the intrinsic privacy of experience, it seems that detectable properties to ascertain the awareness of other systems (i.e., other humans, animals, robots) will remain elusive. However, human-technology integration nevertheless presents the possibility of observational confirmation of the possibility of an aware artificially embodied system. Given the means to replace each and every natural human part with an engineered device or substrate the following *replacement experiment* may be made:

The experimenter begins replacing their parts with engineered substitutes, continuing until they are completely comprised of engineered parts. One of the following two possibilities will be the case:

1) Ability to observe remains as before. In this case a proof is had (by the observer that underwent the replacement experiment) of the possibility of an aware artificial system.

2) No ability to observe remains. In this case the original observer has been destroyed.

The above described experiment offers a means to end the debate regarding the possibility of aware artificial systems simply in that a human observer who is able to transfer their embodiment to artificial devices and substrates cannot argue against the possibility of aware artificial systems. Currently, skeptics of the possibility of aware artificial systems may argue that when one carries out the replacement experiment sufficiently far, the following scenario necessarily results

> You find, to your total amazement, that you are indeed losing control of your external behavior. You find, for example, that when doctors test your vision, you hear them say "We are holding up a red object in front of you; please tell us what you see." You want to cry out "I can't see anything. I'm going totally blind." But you hear your voice saying in a way that is completely out of your control, "I see a red object in front of me" . . . Your conscious experience slowly shrinks to nothing, while your externally observable behavior remains the same. [17]

Realization of the possibility of actually running the replacement experiment will offer the skeptic a means of testing their prediction that 2) necessarily results. The following scenario, or some variant of it, would put to rest the skeptic's reservations regarding the possibility of aware artificial systems

> Layer after layer the brain is simulated, then excavated. Eventually your skull is empty, and the surgeon's hand rests deep in your brainstem. Though you have not lost consciousness, or even your train of thought, your mind has been removed from the brain and transferred to a machine. [18]

Via realization of such a scenario, human-technology integration offers the only known experimental means of ending the debate regarding the possibility of aware artificial systems.

1.7 Conclusions

The human-technology integration approach toward artificial systems with human-like performance has been introduced and discussed in terms of example products by which it currently proceeds. Predictions regarding the results of continued development of human-technology integration have been explored, with attention to the possibility of resolution of the debate over the possibility of aware artificial systems.

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