There is a general dichotomy in popular culture on the future of robotics and artificial intelligence: the Humans-Against-the-Machines scenario versus the We-Become-Them scenario. The likely scenario is the latter, which is compatible with an optimistic posthuman world. However, the technological and cultural paths to robotic integration still have many problems and pitfalls. This essay focuses on Human Robot Interaction issues that apply to adoption of robots in many aspects of life as well as adoption of robotics into humans themselves. The main message of the essay is that the evolution of intelligent species is dependent on interfaces.

Several months ago, on a Sunday afternoon, I set out on a perilous adventure in Harvard Square – mission objective: haircut. The journey ended at the only place open, a hair salon of no distinction. As is typical of the haircutting persuasion, the hairdresser assaulted me with chit chat. I told her that I work for a robot company.

"So, do you think robots are going to take over and stuff?" she said.

This saddened me. I informed her that it was far more likely that humans will become robots. This has been explored in "popular" science and technology books and articles by various roboticists and artificial intelligence (AI) researchers (Moravec 1988, 1999; Minsky 1994; Brooks 2002). Unfortunately, it appears that the notion of evil AI – which is always accompanied by murderous robots – has been filtered into the collective mindset, regurgitated and re-swallowed several times (perhaps more so in certain countries like the United States than in others).

The hairdresser may have actually meant that robots would take over by replacing humans in every single job on Earth in a short period of time. However, it is much more likely that humans will be advancing while robots advance, and in many cases they will merge into new creatures. There will be new people,

new kinds of jobs, new fields, new industries, societal changes, etc. along with the new types of automation.

Certainly, we always need critics to question what safety measures and ethical considerations have been made for each robotic advancement. But why has the story of AI turning against its creators become so commonplace? Is it a meme infecting as many minds as possible? (*Memes* are cultural entities which reproduce like viruses. The ones that spread the most are self-serving, not necessarily truthful or useful for the hosts.) Perhaps the story is believable because most people are still far removed from the realities of robotics and AI. Millions of people have robots in their homes and the number is increasing. However, millions don't.

Somehow the tribal notion of Us-Versus-Them co-exists with the contradictory cultural attraction to robots. A lot of us like the romantic concept of human level intelligent robots, and find the slightly less romantic real robots to be fascinating. For example, although Hollywood is known for entertaining us with technology disasters, several movies show intelligent robots increasing the standard of living and in some cases actually saving humans; for example:

I, Robot
Transformers
Stealth
Star Trek: Nemesis
Star Wars: Episode IV
Forbidden Planet
The Hitchhiker's Guide to the Galaxy
Sleeper
Robot Stories
**batteries not included*
Serenity

Sometimes the robots become more human themselves, for instance:

Data (*Star Trek: The Next Generation*)
Andrew Martin (*The Bicentennial Man*)
Johnny 5 (*Short Circuit*)
the T-800 (*Terminator 2: Judgment Day*)
Sonny (*I, Robot*)
Edward Scissorhands (*Edward Scissorhands)*
V.I.C.I. *(Small Wonder)*

And sometimes movies and television show us humans who use robotics to replace body parts or augment themselves, for instance:

The Six Million Dollar Man
Star Wars (Episode II, Episode III, Episode V)
Robocop
Star Trek: The Next Generation and *Star Trek: Voyager*
Inspector Gadget
Cowboy Bebop
Ghost in the Shell
Wild Wild West
Spider-Man 2

I, Robot

Has the scenario of robotic overlords become nothing more than a joke? Indeed, it is a popular Internet joke to post variants of "I, for one, welcome our robotic overlords." This meme mutated from the original joke in a Simpsons episode ("Deep Space Homer") which had nothing to do with robots. Here are some choice instances I've seen:

> "I, for one, welcome our new biscuit-terminating robotic overlords."
> "I for one welcome our new robot lawyer overlords."
> "I, for one, welcome our new robot cockroach overlords."
> "I, for one, welcome our new Justicetron 3000 overlords."
> "I, for one, welcome our new celebrity Japanese robot savior overlords."
> "I, for one, welcome our new buzzing robotic overlord hive-mind swarm."
> "I, for one, welcome our new geriatric and quadriplegic robot-suit overlords."

The notion of robots turning on their masters seems both silly and a bit scary at the same time. Robots are part of our culture, largely in fiction, but recently also in real life. To think that the human species itself would be in danger from a particular type of machine is to ignore how humans have integrated machines into their lives, and increasingly into their bodies. It is irrelevant whether a person or group involved in a conflict is partially or completely artificial. Conflict is a problem regardless of the tools used.

Currently, saleable robots, which were once limited to automation (such as in car factories) and research labs, have entered many other domains. In the last decade there have been many popular robot toys and artificial pets. In the last five years, domestic robots, such as lawn mowers and vacuum cleaners, have been selling well. The last decade has seen the use of remote control and autonomous robots increase in several militaries of the world, and the plans are to keep those numbers growing. Robots are also key to space applications, such as autonomous spacecraft, radio control builders/fixers for space stations, and mobile robots investigating the surface of other planets.

Some areas of robotics are also complementary to medical advances, such as bionic limbs, which we will return to later in this essay. In the last couple years, many robot researchers have cited statistics about the increasing numbers of elderly people compared with a decreasing number of younger people, especially in Japan and the United States. Basically, if the trends continue, there will be nobody to take care of the old people. It appears we need technology developed right now in order to support the elderly; various types of robots would fill these needs. One would hope robots not only keep disabled and/or old people alive, but also allow them to regain desired levels of youthful and/or satisfying activity. Researchers are already working on therapeutic (both psychologically and physically) robots.

So it is not an outlandish statement to say that most humans alive today, or at least their children, will be affected by robots. If nothing else, they will have interacted with a self-contained mobile robot or a robotic device. And these human-robot interactions are a relatively new phenomenon. We are not only interacting with machines more often, but the machines are becoming smarter, more mobile, and more capable.

These interactions require interfaces. Interfaces enable human-robot interaction – not only are interfaces necessary, but they have to be designed to accommodate human minds and human bodies.

What are Interfaces?

This is the interface problem – how do you get different types of things to talk to each other? Furthermore, how do you get them to understand each other enough to make something worthwhile happen?

Let us define "interface" with a fictional situation:

Bob is leading a team to engineer a transporter robot. This robot has a specific application: it picks an object up, and moves it to a destination. Mary wants to talk to the robot when it is finished. She wants to tell it what to pick up and where to deliver it, with a minimal amount of effort on her part.

There are two types of interfaces in this situation. The Bob type of interface is that of integration. Designing and building the robot requires connecting components. Without connections, and without interfaces to enable connections, one does not have much of a robot. One has a box of parts. The interfaces needed translate information or power. They could be any mixture of mechanical, electrical, or software. Some interfaces enable software written in different programming languages to be linked together. Some interfaces are "black boxes" that translate between different software and/or electrical protocols. Some convert analog signals to digital signals or vice-versa. And so on. The whole point of an interface is that it operates at the nexus of two or more different objects. For the Bob type of interface, in contrast to the Mary type (described later), these objects being connected are inanimate components or computer programs.

Interfaces are also the key for making systems modular, reusable, and extensible. Interfaces hide the guts of an object from the outsiders communicating with it, so that internal changes don't ruin the connection to the outside. Here's an analogy:

A newspaper delivery service promises to deliver the paper in a certain time range every morning. On one side of this promise is the subscriber, who expects the paper without a care for the problems of the delivery service or the actual person who makes the drop. On the other side is the delivery service, which is part of a system involving many people, services, companies, vehicles, etc. There is a contract, and no matter what changes happen on the delivery side, they are still obligated to meet their promise.

Now, back to Bob and Mary. The Mary type of interface is that of creatures interacting. The participants may be animals (including humans), machines, humans with machine parts, machines acting in the service of humans, etc., in various combinations. There may be many creatures in an interaction, or only two. One may be commanding the other to do something, or the interaction may be that of conversation. One or more parties may be teaching one or more other parties how to do something.

Consider this metaphor: interfaces are masks. An interface is a way for a person or object to pretend to be something else when interacting with another person or object. Interfaces don't always seem like masks, however. Sometimes what we call an interface is simply a middleman or translator that helps transport messages back and forth. Often what we call the interface is simply the place where two objects meet, even if there is no special place for the objects to connect. For instance, imagine a bunch of bubbles floating around, bumping into to each other. When a bubble attaches to another bubble, there is patch of shared surface. This is a kind of interface.

Another way to interface is through emulation. An emulator is a program that makes a computer pretend to be another kind of computer. For example, a typical desktop PC can emulate various Nintendo, Sega, Sony, etc. game consoles. Most computer programs are compiled for a specific type of processor. But with an emulator, a totally different processor can run that program.

Interfaces are also generators of abstractions, which, if wielded correctly, can make the system "behind" an interface much easier to use. For example, graphical user interfaces (GUIs) are ubiquitous features of personal computers and many other computing devices, such as cellular phones and car navigation systems. A GUI is software that represents computer information with human-understandable images and animations. A GUI also allows a human to communicate with the computer via input devices, e.g. mice, keyboards, joysticks, touchscreens, etc. These inputs are also represented visually (and sometimes through audio as well).

Mary's type of interface has to do with humans using everyday items. Often everyday objects are artificial constructions, and often those are machines. One can branch out from this type of interface to many subtypes:

Human – machine
Human – portable machine (laptop computers, cell phones, PDAs, gameboys)
Human – ubiquitous machines (computers embedded in buildings, vehicles, and clothing)
Human – machine embedded in human body
Human – mechanical prosthetic
Human – robotic prosthetic
Human – autonomous robot
Human – cyborg (a human with artificial parts)
And so on…

In the list above, one may notice a trend: humans interacting with robots and/or robotic parts. There is a spectrum from the Bob types – such as replacing failing internal organs with artificial ones – to the Mary types – for instance a human playing with a robot.

Human-Robot Interfaces

Human-oriented interfaces are essential to a positive human robot experience. Even the best machine is useless if the user can't operate it. Even if the machine was as autonomous as a human, it would still need a set of interfaces that allow flexible two-way communication. The humans and robots involved may not realize how dependent they are on layers of well-developed interfaces. Indeed, it is an indication of good design when the user does not notice the user interface. And one may hesitate to refer to herself as a "user" when dealing with a sufficiently autonomous and competent robot.

If a new robotic product requires the entire human race to radically mutate in order to use it, the product will sell like armpit-flavored hotcakes, which is to say, not at all. But if a new robot can emulate a human, then the entire human race (well, most of it) can by default interact with it. The extreme end of user interface design is an android indistinguishable in behavior, appearance, smell, taste, sound, and touch from a human.

There are two primary classes of human-robot interfaces:

1. The human's interface with non-standard equipment and robots.
2. The interface between highly-modified humans to stock biological humans.

Number one is basically the Mary type of interface described in the previous section. This class includes hardware, software, and methods for humans to converse with robots, software agents, and miscellaneous ubiquitous computing devices (computers and networks embedded all over the place). But Class 1 also includes a form of the Bob interface: the "non-standard equipment" refers to devices used close to a human body, in some cases actually attached or implanted.

The second class of human-robot interface depends on Class 1, namely the non-standard equipment interfaces. Body interfaces—especially involving the nervous system—supply the means to replace all failing biological organs with new working ones, replace existing parts with more advanced ones, and integrate entirely new parts for previously nonhuman abilities. At the moment, people with artificial organs, pacemakers, ear implants, and prosthetics are still accepted as human. You can hold a conversation with somebody and not even know they have transplanted organs. But as we get better at interfacing with human biology, and markets change, it is possible that a highly-modified human may no longer be able to hold a conversation as we know it today. It is difficult to imagine what kinds of communication they will have to replace written language, speech, facial expressions, gestures, body posture, etc. Infrastructures such as the Internet have enabled new interfaces around language, such as e-mail and instant messaging. Some humans may choose to interact completely "online." They will appear to others, who may be radically different, as virtual characters. Various middleman programs might automatically translate between various languages, protocols, and intelligence types. It is also foreseeable that humans with enough gadgets or implants will use wireless networking infrastructures for techno-telepathy – i.e., nearly instantaneous reading and writing of information between people without any physical effort (except for brain cells).

Parts and Service

The Iraq and Afghanistan wars have resulted in thousands of injured U.S. soldiers; the percentage of survivors has increased compared to previous wars, but the rate of amputation has doubled (Mishra 2004). The Defense Advanced Research Projects Agency (DARPA) has two "Revolutionizing Prosthetics" programs running right now, one for 2007 and one for 2009 (Pope 2006). Both arms are intended to have neural control and feedback; the second one is supposed to be more advanced, and it should be usable for daily living tasks. Since this essay was originally written in 2006, a prototype of the first arm (now known as the "Luke arm" in reference to Luke Skywalker) has been successfully demonstrated by DEKA (Adee 2008).

Soon an amputee with appropriate health insurance or money will have two choices (if they wish to regain their previous state of activity): 1. Regeneration, or 2. Bionic install.

Biological regeneration will allow you to regrow a missing body part, either directly off of your body, or in a lab where it is then transplanted to your body. Bionic prostheses are electromechanical contraptions roughly the same size and shape as a stock biological human arm, that afford the same degrees of freedom, strength, speed, etc. as a typical human arm.

The ultimate goal is for bionic prosthetics to be interchangeable with natural appendages. However, *interchangeable* is a tricky thing. It requires a lot more neurotechnology research on the interfaces. In addition, there also has to be intelligent programming in the bionic arm to replicate that which we take for granted with our natural nervous systems. Typical adult humans give very high level goals to their appendages. You just grab something – you don't think about it. Indeed, when you start thinking about everyday motions or sporting actions (like catching a ball), you are forcing your slow general purpose cognition to micromanage a procedure that can be done much faster and better by autonomous subsystems optimized by evolution. So artificial systems also have to replicate the autonomous processes occurring in natural brain-arm-hand systems, such as automatically reacting to slippage when gripping (Dario et al. 2005).

Of course, robots can also help in avoiding many disasters and attacks resulting in lost limbs by being used for the Three D's—tasks that are Dangerous and/or Dirty and/or Dull.

Dirty Robots

Besides all the current and upcoming commercial robots, the number of military robots in service is increasing, and a wide array of new robots is currently being developed for various defense programs.

The U.S. Army, Navy, and Marine Corps all have several remote controlled conveyances of many different sizes and shapes. These have cameras and other sensors on them, which are useful for reconnaissance, bomb sniffing, biohazard sniffing, sniper detection, guard duty, telepresence, etc. They also have appendages, such as arms, used for a range of tasks, for example to disarm or detonate improvised explosive devices.

Already we have a whole range of robotic vehicles in use: unmanned aerial vehicles (UAVs), unmanned combat aerial vehicles (UCAVs), unmanned ground vehicles (UGVs), unmanned ground combat vehicles (UGCVs), remote operated underwater vehicles (ROVs), Unmanned Surface Vehicles (USVs), autonomous underwater vehicles (AUVs), and so on. Most of these are teleoperated, i.e. remote controlled by a human, usually through a radio link or a fiber optic tether. The human robot interface is primarily through the OCU (Operator Control Unit). Most of the UAVs in service require multiple pilots sitting down in a ground control station (GCS), which contains several computers, screens, keyboards, joysticks, etc.

One of the current goals in the American military is for new control units to be so easy to use that any soldier – without any specific robot training – will be able to command the robot to do useful tasks. Of course, making something easy to use – especially in harsh and stressful contexts – is not easy. Yet another major military goal is to enable a single person to control multiple unmanned vehicles. The user interface will be a major part of that, and will have new interfaces to go along with more layers of intelligent software. Both the operator control units and the robots themselves will be more autonomous, and will be capable of working in teams with other robots and other humans.

Increased autonomy will affect the human robot interaction, mostly for the better. If the robot can navigate itself, then the operator doesn't have to worry about it. The operator can then focus on the subject at hand, such as searching for victims in wreckage, or disarming a bomb. Some operators will have even higher level strategic goals and will expect the robots to perform tasks on their own, only interrupting the human for critical events.

Lifting Interfaces

We have some very useful robot interfaces already. But they are largely based on the existing human-computer interaction mechanisms, such as GUIs. Although GUIs are certainly better for most users than typing commands manually, they are often not designed properly. They are also far behind the potentials researchers are exploring. One example of interface technology being researched is called *affective computing*, which is about using sensors and software to understand and accommodate human emotions and moods (Picard 1997). Another example is called *commonsense reasoning*, which aims to enable computers and robots to understand and manipulate (or talk about) everyday objects and situations in a fashion similar to humans, or at the very least support user interfaces that seem less constricted and more helpful for tasks than computers have been up till now (Lieberman et al. 2004).

Then there are the various physical interface devices. The standard set of human-computer interface hardware has been largely the same for the past two decades: keyboards, mice, and monitors. Sometimes we use joysticks and gamepads and steering wheels, some of which have force-feedback. Peripherals include speakers, headphones, microphones, printers, scanners, digital cameras, digital music players,

PDA links, etc. All these devices that we can plug into our computers are nice, but what about all the futuristic interfaces that we see in movies?

Some of those "futuristic" interfaces are available now in the present. For instance, continuous speech recognition software has been available for years. You can now buy lightweight, low power HMDs (Head Mounted Displays), some of which have tiny head tracking gyroscopes in them. The gestural hand-controlled display shown in the film *Minority Report* is also not so futuristic – it was inspired by a real working project. You can already buy wireless mice with gyroscopes that sense wrist motion gestures. The "Wiimote" (the controller for Nintendo's Wii game console) is based on that technology. Then there are the haptic (touch feedback) interfaces, such as control devices that let you virtually sculpt. And there's electronic ink now being embedded in various devices, and interactive paper being developed.

Eventually, the display technologies and the wireless network and tracking infrastructures in our environment will allow us to move *augmented reality* out of the lab and into society. Augmented reality consists of computer graphics overlaid on top of your view of reality, updated in real time based on the locations and orientations of the real objects, thus providing radical new forms of human-robot, human-architecture, and human-human interfaces. Early versions of this technology allow mechanics to see wireframe drawings superimposed on the view of an engine along with repair instructions. Researchers have experimented with augmented reality for video games and also for mobile robot control.

These developments are but a hint of the possible improvements in computer interfaces that also apply to robot interfaces.

Closer

How close can an artifact get to becoming part of you?

I've been skiing since I was two years old. I'm not always that graceful, but I rarely fall down. The skis do what I want, for the most part – I'm deciding and problem-solving at higher levels of planning, for example when I have to solve the problem of how to traverse a very difficult tree and rock-ridden "trail." I am looking for immediate obstacles and provocative terrain, making temporary plans of which way to go.

But I am not totally disconnected from the skis and the lower level acts of skiing. Indeed, one must be sensitive to rapid changes in the snow, especially since one can't always see when the snow changes. It is a type of instant adaptation to the changes in the situation. I suspect this kind of skiing is a very different experience than the first time ever skiing – it's a familiarity from over two decades of training. To a degree, the skis become an extension of your feet. The skis are both sensors and end effectors. The sensors give you hints on how to adjust the force and balance etc. on the effectors dynamically. Unfortunately, humans usually have to practice for many years to acquire the part-of-me tool skills.

Part of the skiing example is the ability to "do" something, and not be self-aware about it. Your brain is still making it happen – it's just that the brain parts and processes comprising consciousness are no longer paying attention to the details. Consciousness no longer has to walk through all the steps; it no longer has to micromanage the activity. You've optimized, generalized, compiled and pushed down this story to the anonymous working class of your mind. You say "drive" and behold: you're driving. But when you learned to drive, it is likely you weren't quite as smooth, and weren't as capable of secondary tasks.

A tool (robotic or otherwise) that integrates closely with a user's natural physiology and psychology can greatly narrow what is called the Gulf of Execution (Norman 1988). It must be obvious which user actions are available and what actions the system does in response. These system actions should

correspond with the user's intentions. Feedback of the actions helps narrow another gap – the Gulf of Evaluation (Norman 1988). The user must be able to understand whether the system is actually doing the correct functions and what the status of the system is. And the status of the system has to be relevant information that fits into the user's expectations and understanding.

Are Robot Interfaces Dangerous?

Many humans have had interpersonal communications with robots. The last decade has shown us human-robot forms of *Aichaku* – a Japanese term for the feeling of attachment with artifacts we use, possibly growing over time (Maeda 2006). For example, I have seen a child pet an iRobot Packbot. People name their bomb disposal robots, but that shouldn't be surprising, since a lot of people name their cars. If there is no affection with current robot products, there is at least amusment: one can find dozens of videos on YouTube of vacuuming robots interacting with pets. Various robots in the domains of research, entertainment, children's toys, eldercare, and virtual pets have established human-robot relationships, however flimsy and fleeting.

To date, robots are quite limited in mental capabilities compared to humans and other animals. An interface can only go so far before the underlying mechanism's limitations are evident. This is similar to the notion of "leaky abstractions" (Spolsky 2002). We are presented with seemingly friendly, usable, reliable, complete systems. But in reality we are interacting with the top layer in a stack, in which lower layers are quite unreliable and unfriendly. Sometimes when things fail in the hidden background framework, they leak through the cracks to the front, shattering the user experience and interrupting the task at hand. You might feel foolish or abused when your cute, lively robot runs out of battery power and freezes, or it can't hold a conversation for more than 30 seconds, or its emotional expressions are inappropriate for various situations because its intelligence is on par with a worm. As Sherry Turkle (2006) points out,

> If our experience with relational artifacts is based on a fundamentally deceitful interchange (artifacts' ability to persuade us that they know and care about our existence) can it be good for us? Or might it be good for us in the "feel good" sense, but bad for us in our lives as moral beings?"...These questions ask what we will be like, what kind of people are we becoming as we develop increasingly intimate relationships with machines.

The various expressive robots of the past decade crudely emulate emotions, which when combined with our natural tendency to anthropomorphize (credit inanimate objects with human attributes) results in what seems like an interaction with a live organism. But emotional interfaces are not new. Many products and media specifically poke at emotional triggers. Books and movies will compel the readers or viewers to experience emotions, to root for the protagonist, to sympathize with the characters they like, and so forth. A large part of the effectiveness of novels is that they are largely interactive – the writer is more of a guide, and although you can discuss a novel with someone else in common terms, your experience of it is unique.

So emotional manipulation through various media is not new. Certain applications of robotics will continue that heritage. As always, individuals and societies have to choose wisely who they have relationships with and what media they saturate themselves in. Tapping into the emotional brain is necessary for better interfaces. But future robots will improve this interface by also monitoring, modeling, and adjusting to human emotions. It will be a "two-way street" – the robots and computers will have their own emotional architectures that humans will deal with as they deal with other humans. At the same time, our human emotional frameworks will change as we evolve with technology.

The Interface Future

What psychological twisting will occur to individuals as they adapt to more frequent and necessary interactions with modified humans, autonomous machines, and the spectrum of organisms in between? Will each generation be better suited to the situation than the previous by being born into the calm eye of the hurricane of cultural change?

Humans have fairly common physiological and psychological development stages during childhood. But even that will change with the options of intelligence amplification and more effective ways to learn (and teach). Perhaps some of the new ways to interface with other people (be they mostly natural or mostly artificial) and the environment will enable better and faster learning.

We should be prepared, not repulsed, by a future populated by crossbreeds of humans, animals, robots, and everything in between. Some will be virtual. Some of the more extremely changed people (posthumans) may not even be recognizable by others as human.

This strange new network of organisms will require a lot of strange new interfaces. But are interfaces enough to smooth out this potential mass confusion of identity and origins? At the very least, people need to communicate with other people and control their tools and environments. Still, if too many things change and new beings are created so fast that the "world spins" every year, how will people keep up? Will this be a constant state of emergency, in which the slow and frail are trampled?

Interfaces can enable chaos and conflict. Simultaneously, interfaces enable efficiency and understanding. An interface-oriented point of view is necessary to advance our world with robotics.

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