Ethics and Information Technology (2005) 7:111–119
DOI 10.1007/s10676-006-0008-0 © Springer 2006

Why we need better ethics for emerging technologies

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Abstract. Technological revolutions are dissected into three stages: the introduction stage, the permeation stage, and the power stage. The information revolution is a primary example of this tripartite model. A hypothesis about ethics is proposed, namely, ethical problems increase as technological revolutions progress toward and into the power stage. Genetic technology, nanotechnology, and neurotechnology are good candidates for impending technological revolutions. Two reasons favoring their candidacy as revolutionary are their high degree of malleability and their convergence. Assuming the emerging technologies develop into mutually enabling revolutionary technologies, we will need better ethical responses to cope with them. Some suggestions are offered about how our approach to ethics might be improved.

Introduction

New technological products are emerging. We learn about them regularly in the news. Information technology continually spawns new and popular applications and accessories. Indeed, much of the news itself is produced and transmitted through ever newer and more diverse information technology. But it is not only growth in information technology that is salient; other technologies are expanding rapidly. Genetic technology is a growth industry with wide applications in foods and medicine. Other technologies, such as nanotechnology and neurotechnology, are less well established but have produced striking developments suggesting the possibility of considerable impact in the not too distant future.

The emergence of these potentially powerful technologies raises the question about what our technological future will be like. Will the quality of our lives improve with increased technology or not? I believe the outcome of technological development is not inevitable. We at least collectively can affect our futures by choosing which technologies to have and which not to have and by choosing how technologies that we pursue will be used. The question really is: How well will we choose? The emergence of a wide variety of new technologies should give us a sense of urgency in thinking about the ethical (including social) implications of new technologies. Opportunities for new technology are continually arriving at our doorstep. Which kinds should we develop and keep? And, how should we utilize those that we do keep?

The main argumentation in this paper is to establish that we are living in a period of technology that promises dramatic changes and in which it is not satisfactory to do ethics as usual. Major technological upheavals are coming. Better ethical thinking in terms of being better informed and better ethical action in terms of being more proactive are required.

Technological revolutions

"Technology" is ambiguous. When speaking of a particular kind of technology, such as airplane technology, we sometimes refer to its paradigm and sometimes to its devices and sometimes to both. A *technological paradigm* is a set of concepts, theories and methods that characterize a kind of technology. The technological paradigm for airplanes includes the concept of a machine that flies, the theory of aerodynamics, and the method of using surfaces to achieve and control flight. A *technological device* is a specific piece of technology. The Wright brothers' airplane and commercial jetliners are examples of technological devices. Technological devices are *instances* or *implementations* of the technological paradigm. *Technological development* occurs when either the technological paradigm is elaborated in terms of improved concepts, theories, and methods or the instances of the paradigm are improved in terms of efficiency, effectiveness, safety, etc. Of course, technological development has occurred in numerous technologies over thousands of years.

But in some cases technological development has an enormous social impact. When that happens, a *technological revolution* occurs.[1] Technological revolutions do not arrive fully mature. They take time and their futures, like the futures of small children, are difficult to predict. We do have an idea of how children typically develop and likewise I believe we have an idea of how revolutions typically develop. I will try to articulate that conception in terms of a plausible model of what happens during a typical technological revolution.

We can understand a technological revolution as proceeding through three stages: the introduction stage, the permeation stage,[2] and the power stage.[3] Of course, there are not sharp lines dividing the stages any more than there are sharp lines dividing children, adolescents, and adults. In the first stage, the *introduction stage*, the earliest implementations of the technology are esoteric, often regarded as intellectual curiosities or even as playthings more than as useful tools. Initially only a few people are aware of the technology, but some are fascinated by it and explore its capabilities. Gradually the devices improve and operate effectively enough to accomplish limited goals. Assuming the technology is novel and complex, the cost in money, time, and resources in using the technology will typically be high. Because of these limitations the technology's integration into society will be minor and its impact on society will be marginal.

In the second stage, the *permeation stage*, the technological devices are standardized. The devices are more conventional in design and operation. The number of users grows. Special training classes may be given to educate more people in the use of the technology. The cost of application drops and the development of the technology begins to increase as the demand for its use increases. The integration into society will be moderate, and its overall impact on society becomes noticeable as the technological devices are adopted more widely.

Finally, in the third stage, the *power stage*, the technology is firmly established. The technology is readily available and can be leveraged by building upon existing technological structures. Most people in the culture are affected directly or indirectly by it. Many understand how to use it or can benefit from it by relying on people who do understand and use it. Economy of scale drives down the price and wide application provides pressure and incentive for improvements. The integration into society will be major and its impact on society, if it is truly a revolutionary technology, will be significant. The impact of the technology on society is what marks it essentially as revolutionary. Toasters have undergone technological development, but toaster technology has not had a significant level impact on our society. As wonderful and improved as toasters are, there is no toaster revolution; whereas there has been a technological revolution due to developments of the automobile and electricity. Take toasters out of society and not much is changed. Remove automobiles or electricity and our contemporary society would have to make massive adjustments.

This tripartite model for an open technological revolution is summarized by Table 1. Social impact inevitably reflects the other factors mentioned in the table and in addition includes the effect the technology has on the behavior and practices of the society. A technological revolution has a large scale transforming effect on the manner in which a society functions.

In giving this description of technological revolutions I have been making some assumptions which need to be made more explicit. This is a model of *open* technological revolutions in the sense that the revolution occurs in an open society and the technology is accessible directly or indirectly by the general public as a good or service over time. I have been assuming a liberal democratic state in which market forces, even if regulated, play an important role. These are the conditions under which technological revolutions can flourish. The automobile revolution and electrification revolution are examples of reasonably open technological revolutions. In closed revolutions the access to the technology remains severely restricted by social, political, or economic forces. For example, a ruling elite or a military may maintain control by limiting access and use of particular technologies. The development of nuclear weapons would be an example of a closed technological revolution. Closed technological revolutions by definition will control the dispersal of the technology so that they are unlikely to proceed through all of the aspects of the permeation and power stages in this model. Here we will be considering open technological revolutions granting, of course, that the

[1] The term "revolutionary technology" is used colloquially sometimes to describe new and improved technological devices. A new mousetrap might be said to be "revolutionary" if it catches many more mice than earlier models. I will use "revolutionary technology" in a much stronger sense requiring that the technology have significant social impact.

[2] James H. Moor, "What Is Computer Ethics?," *Metaphilosophy* 16.4 (1985).

[3] James H. Moor, "The Future of Computer Ethics: You Ain't Seen Nothin' Yet!," *Ethics and Information Technology* 3.2 (2001).

Table 1. Stages of an open technological revolution

	Introduction	Permeation	Power
Devices	Esoteric	Standardized	Leveraged
Users/Beneficiaries	Few	Select	Many
Understanding	Elite	Trained	Common
Cost per Use	High	Medium	Low
Usefulness	Limited	Moderate	High
Integration into Society	Minor	Moderate	Major
Social Impact	**Marginal**	**Noticeable**	**Significant**

openness of a revolution may be a matter of degree and may vary across societies and time.[4]

Revolutions do not come from nowhere or vanish suddenly into nothing. A pre-revolutionary period exists in which basic concepts and understanding develop that make the introduction stage possible. A post-revolutionary period exists in which the technology is well established. Development may still be made, but the significance of the technology will not increase proportionally and eventually may decline or disappear if the technology is replaced with even better technology.

As an example of a technological revolution consider the computer/information revolution. In the pre-revolutionary stage many concepts and devices were developed that lay the groundwork for the revolution. Concepts from the development of mathematics to the theoretical analysis of computing by Alan Turing were crucial preparation for computing technology to develop. Early computational devices from the abacus to Gottfried Leibniz's calculating machine to Charles Babbage's difference engine were precursors illustrating that machines could be used for calculation. But the computer revolution, as we think of it in modern terms, began around World War II. The early machines were certainly esoteric. In Britain the Colossus computer, the first large-scale electronic digital computer, was specialized to break codes. In the United States ENIAC (Electronic Numerical Integrator and Computer) was used in some calculations for the Manhattan Project as well as calculations of ballistic trajectories.

After World War II computers were developed in an open environment for more general purposes and the introduction stage into society really began. Through the 1950's and 60's large mainframe computers were used by elite institutions, such as banks, large companies, universities and governments, that could afford them. Improvements in their usability and capability were gradually made but those computers were far from user friendly in today's sense. Input was often done by stacks of punched cards and output was mostly text or even punched tape with limited control over the format. These behemoth machines made some specific jobs easier but in general they were not useful for most activities in the workplace, school, or home. Early projections, even by some who were quite knowledgeable about computers, claimed that only a relatively small number of computers would be necessary for society in the long run.

The permeation stage began with the introduction of personal computers in the late 1970's and early 1980's. Early in this period most homes did not have personal computers though they were found in some schools and offices. Training classes were given to ensure people were computer literate. They were useful for select projects but not particularly useful

[4] The model presented here has similarities to but should not be confused with Schumpeter's well known and controversial model for capitalistic economies. Joseph A. Schumpeter, *Capitalism, Socialism, and Democracy*, 4th ed. (London: George Allen & Unwin Ltd, 1952). Joseph Schumpeter (1883–1950) is a respected economist who analyzed the evolution and cyclic nature of capitalism. Schumpeter developed a rich concept of entrepreneurship. According to him entrepreneurs are essential drivers of capitalism. They innovate not only by improving technological inventions but also by introducing new products, identifying new sources of supply, finding new markets, and developing new forms of organization. With regard to technological development his theory can be described in terms of cycles of invention, innovation, and diffusion. Schumpeter believed that these cycles of capitalism would lead to growth and improved living standards. But, he also believed that regrettably capitalism was likely to destroy itself by attacking freedoms and private property that made capitalism possible.

The model presented in this paper is not aimed at explaining the nature and fate of capitalism. The model here focuses on the nature of open technological revolutions in which a free market is one of the enabling conditions. Schumpeter's model does not distinguish between technological development and technological revolution (toasters vs. computers) which is a central distinction of the model in this paper. Distinguishing the power stage from the permeation stage is crucial in identifying those technologies that have a significant level of social impact and consequently will have the most serious ethical impact.

for many activities even in a well equipped office. The cost of computing dropped compared to the earlier expensive mainframes and the impact computing had in the office was noticeable in that changed procedures for performing routine activities in schools and workplaces on a broader scale.

By 2000 and the years following the shift was being made into the power stage. Most people and homes had computers. A business did not have to be concerned about its customers being computer literate or knowing how to use the web, it could assume this. This basic common knowledge of the web and use of computers could be then leveraged to advertise and sell ordinary products. The cost of computing dropped even more so that many people now own more than one computer and have wide access to computers in public and work places. E-mail is an assumed form of communication. Online commerce and banking is soaring. The web is now a, if not the, standard reference source for information for most people. Computer chips are implanted in us and embedded in our environment. The computer in its many manifestations is thoroughly integrated into advanced society. Thus, the computer revolution provides a nice example of the model of how an open technological revolution unfolds.

To identify a technological revolution one must consider the technological paradigm, the technological devices that instantiate the paradigm, and the social impact of these devices. The paradigm will evolve and be articulated in new ways over time but will be identifiable as alterations of the original version of the paradigm. In the example of the computer revolution, the concept of computation is an essential feature of the basic paradigm. Over time this paradigm has evolved to include parallel processing, genetic algorithms, and new architectures, but these are regarded as different ways of doing computation. To determine what stage is occurring all the devices that instantiate the paradigm for a society at that time need to be considered. Although some devices which implement the paradigm will be more developed than others, the overall status of these various devices needs to be assessed in terms of the items in the table of factors of an open technological revolution. The social impact of the devices instantiating the paradigm is most indicative of the stage of development. Without a significant social impact from the overall set of these devices, the revolution has not yet occurred. Of course, a technological paradigm or device may be said to be revolutionary when it initially appears, but such a remark should be understood as an anticipatory projection into the future. It is an assertion that in the future there will be devices that instantiate the paradigm that meet the conditions of the power stage of a technological revolution.

A technological revolution will have many technological developments within it. Some, perhaps many, of these developments will not be revolutionary under the criteria in the table. They will never reach the power stage. But, some of these embedded technological developments may satisfy the criteria for a technological revolution sufficiently to qualify as subrevolutions within the more general revolution. A subrevolution is a technological revolution that is embedded in another. The subrevolution will have a more specific paradigm that is a restricted version of the general paradigm and will have devices that instantiate its more specific paradigm that will be special cases of the more general revolution. The subrevolution will move through the stages of a technological revolution though possibly not at the same times or at the some rate as the more general revolution in which the subrevolution is embedded.

Consider the mobile cell phone technology as an example of a subrevolution within the computer revolution. In 1973 Martin Cooper made the first call on a portable cell phone the size of a brick and was joking called “the brick”. Few had or wanted one. Mobile phones gradually became smaller and were installed as car phones. This had moderate usefulness at least for those who drove cars and needed to communicate. Today mobile phones are small, portable, and highly functional. They are used to take photographs, text message, play games, and, of course, send and receive phone calls. Mobile phones outsell landline phones in some nations. Many people in advanced societies can and do use them. They are thoroughly integrated into society and are having significant social impact.

The world wide web is another example of a subrevolution within the computer revolution. The concept of the web was established as a paradigm of linked and searchable documents with domains of access on the internet. But its initial impact on society was marginal. For example, one esoteric, but not too exciting, early use of the web in the 1990’s was to watch the level of a coffee pot in a remote location. The world wide web was in the introduction stage. Over the years as devices, such as browsers and web languages improved, the web became more useful and was recognized a place to display and share information. In this permeation stage of the revolution courses were established to train people and companies in setting up their own web pages. A select number found the web useful, but a majority did not. Today, of course, the web provides a much used method of exchanging information and conducting business. The web has reached the power stage. The devices instantiating the web paradigm today support everything from banking to blogging. Having access to the web and knowing how to use it are commonplace. The web is integrated into our lives, useful for most people, and has significant social impact.

Technological revolutions and ethics

Technology, particularly revolutionary technology, generates many ethical problems. Sometimes the problems can be treated easily under extant ethical policies. All things being equal using a new technology to cheat on one's taxes is unethical. The fact that new technology is involved does not alter that. But, because new technology allows us to perform activities in new ways, situations may arise in which we do not have adequate policies in place to guide us. We are confronted with *policy vacuums*. We need to formulate and justify new policies (laws, rules, and customs) for acting in these new kinds of situations. Sometimes we can anticipate that the use of the technology will have consequences that are clearly undesirable. As much as possible, we need to anticipate these and establish policies that will minimize the deleterious effects of the new technology. At other times the subtlety of the situation may escape us at least initially, and we will find ourselves in a situation of assessing the matter as consequences unfold. Formulating and justifying new policies is made more complex by the fact that the concepts that we bring to a situation involving policy vacuums may not provide a unique understanding of the situation. The situation may have analogies with different and competing traditional situations. We find ourselves in a *conceptual muddle* about which way to understand the matter in order to formulate and justify a policy.

An example from information technology will be helpful. Today wireless computing is commonplace. Wi-Fi zones allowing public use are popular and some have proposed making entire cities Wi-Fi areas. We can sit outside in the sun and use a Wi-Fi arrangement to make connections with a network. This is something we couldn't do before. One might at first believe that it is no different than being hardwired to a network. But is it? If one can sit outside in the sun and connect to the network wirelessly, others, assuming there are no security barriers, can as well. Having others so easily connect was not possible when a wire connection was required. A kind of sport has developed called "wardriving" in which people drive around attempting to connect wirelessly to other people's networks especially if they are not public networks. Is wardriving ethical? A policy vacuum exists at least in cases of private Wi-Fi connections.

As we consider possible policies on wardriving, we begin to realize there is a lack of conceptual clarity about the issue. Wardriving might be regarded as trespassing. After all, the wardriver is invading apparently someone's computer system that is in a private location. Conceptually, this would seem to be a case of trespass. But the wardriver may understand it differently. The radio waves are in a public street and the wardriver remains on the public street. He is not entering the dwelling where the computer system is located. Indeed, he may be nowhere nearby.[5] In searching for a new policy we discover we have a conceptual muddle. We find ourselves torn among different conceptualizations each of which has some plausibility.

The relationship between resolving conceptual muddles and filling policy vacuums is complex. In some cases sufficient analogies can be drawn with related concepts and situations so that conceptual confusion is resolved first. In the case of Wi-Fi one might consider various kinds of trespass to determine how similar or dissimilar they are to what occurs in Wi-Fi situations. But resolution through analogies may not be decisive or convincing. Another approach is to consider the consequences of various policies that could fill the vacuum. Some policy may emerge as much better. In which case selecting that policy would not only fill the vacuum but also would likely have an effect on clarifying the conceptual muddle. For example, if one could show that allowing people to employ Wi-Fi connections to use other people's unsecured computer systems caused little harm, then tolerance toward wardriving might be adopted as the correct policy and conceptually wardriving would not be considered trespass. The point is that sometimes a conceptual muddle is resolved first, through analogies or other reasoning, which in turn will influence the selection of a policy. And sometimes the policy is selected first based on analysis of consequences or other justificatory methods and the conceptual muddle is thereby resolved in reference to the new policy.

Let me summarize my position thus far. I have proposed a tripartite model for understanding open technological revolutions. What makes the technological change truly revolutionary is its impact on society. The computer/information revolution nicely illustrates this model. Ethical problems can be generated by a technology at any of the three stages, but

[5] The distance can be quite large. The Guinness world record for Wi-Fi connections is 310 kilometers or about 192 miles. http://www.wired.com/news/culture/0,1284,64440,00.html

the number of ethical problems will be greater as the revolution progresses. According to this model more people will be involved, more technology will be used, and hence more policy vacuums and conceptual muddles will arise as the revolution advances. Thus, the greater our ethical challenge will be during the last stage of the revolution.

This argument is forceful for computing in part because we can see the dramatic effects computing has had and the ethical problems it has raised. But what of the emerging technologies? How do we know they will follow the model, be revolutionary, and create an increasing number of ethical problems?

Three rapidly developing technologies

Genetic technology, nanotechnology, and neurotechnology are three rapidly developing technological movements. Each of these has been progressing for awhile. None of the three has progressed as far as computer technology in terms of its integration and impact on society. Of the three, genetic technology is perhaps furthest along. Genetic testing of patients is common. In vitro fertilization is widely used. Many foods are engineered and more and more animals are being cloned. Techniques for using DNA to establish the guilt of criminals or to free the falsely imprisoned or to identify natural disaster victims are used routinely. Stem cell research is ongoing and promises inroads against heretofore devastating medical conditions. Genetic technology has permeated our culture. But it falls short of the power stage.

Nanotechnology produces materials through manipulation and self assembly of components at the nanometer scale. Progress has been made in terms of the production of items such as nanotubes, protective films, and biosensors. Some of these products currently have practical benefits, and others still being developed are not far from practical application. Some researchers expect that in the future some medical testing will be done through ingested nanobiosensors that can detect items such as blood type, bacteria, viruses, antibodies, DNA, drugs, or pesticides. The fulfillment of the overall promise of nanotechnology in terms of new products is a considerable distance from the power stage.

Similarly, neurotechnology has been evolving with the developments of various brain scanning devices and pharmaceutical treatment techniques. We know much about brain functioning. Although brain surgery has been common for a long time, neurotechnology still remains somewhat far from the power stage of a technological revolution.

Although these technologies are not fully developed, it is not unreasonable to expect that they will continue along a revolutionary path and bring with them an increasing cluster of new ethical issues. First, all of the technologies possess an essential feature of revolutionary technology, namely they are propelled in vision and in practice by some important generic capability. All of these technologies are malleable in some way. Consider computing technology again as an example. Computing has this generic capability in terms of logic malleability. Computers are logically malleable machines in that they can be shaped to do any task that one can design, train, or evolve them to do. Syntactically, computers are logically malleable in terms of the number and variety of logical states and operations. Semantically, computers are logically malleable in that the states and operations of a computer can be taken to represent anything we wish. Because computers given this logical malleability are universal tools, it should not be surprising that they are widely used, highly integrated into society, and have had an enormous impact.

Each of the developing technologies mentioned have this generic capability as well. They have important forms of *malleability*. Genetic technology has the feature of life malleability. Genetics provides the basis for generating life forms on our planet. If this potential can be mastered, then genetic diseases can be cured and resistance to non-genetic diseases can be improved. The quantity and quality of our lives can be improved. Clearly a significant impact on society would take place. Indeed, life malleability offers the possibility of enhancements of current forms of life, the creation of extinct forms, and the creation of forms that have never existed.

Nanotechnology has the generic capability of material malleability. The historical vision of nanotechnology has been that in principle material structures of any sort can be created through the manipulation of atomic and molecular parts as long the laws of nature are not disobeyed. If we are clever and arrange the ingredients to self-assemble, we can create them in large quantities. Some researchers suggest that nanostructures could assemble other nanostructures or could self-replicate. How possible all of this is remains an open empirical question. But if the pursuit comes to fruition, then machines that produced many of the objects we desire but which are difficult to obtain might be a possibility. In this event nanotechnology would have a truly significant impact on society.

Neurotechnology has the potential generic capability of mind malleability. If minds are brains and neurotechnology develops far enough to construct and manipulate brains, neurotechnology could be the most revolutionary of all of the technologies. Minds could be altered, improved, and extended in ways that are difficult for our minds to comprehend.

All of these technologies are grounded in visions of enormous general capacities to manipulate reality as summarized by the following table:

Information Technology	Logic Malleability
Genetic Technology	Life Malleability
Nanotechnology	Material Malleability
Neurotechnology	Mind Malleability

All of them are conducted under paradigms suggesting great power over and control of the natural world. Each could bring about worlds unlike those we have ever experienced.

The second reason in addition to malleability that these areas are good candidates for being revolutionary technology is that these technologies tend to *converge*. The technologies reinforce and support each other. Each of them is an enabling technology. There are at least three ways that these technology converge. In one kind of convergence a technology serves as a *tool* to assist another technology. An excellent example of this is illustrated by the human genome project. The purpose of the project was to discover the sequences of the three billion chemical base pairs that make up human DNA and identify the 20,000–25,000 genes in human DNA. All of this was accomplished ahead of schedule because of enabling tools – computers that analyzed the data and robots that manipulated the samples. Because the human genome is now known along with other genomes, genetic technology has been catapulted ahead. Some believe that genetic technology in turn can be used as an enabling tool in nanotechnology. Because DNA serves as a way to order the arrangement of molecules in nature, its sequencing capability might be adapted by nanotechnologists to organize and orient the construction of nanostructures out of molecules attached to the DNA.

Convergence of technology may also occur with one technology serving as a *component* of another. When computer chips are implanted in brains to assist paralyzed patients to act or to relieve tremors or to restore vision, the convergence of technologies produces miraculous outcomes through the interaction of neurology and computing. Finally, convergence may occur taking aspects of another technology as a *model*. Thus, some computing technology employs connectionist architecture that models network activity on neural connectivity, and other computing technology employs genetic algorithms that simulate evolutionary processes to produce results that are more fit at doing particular jobs.

Thus, convergence may involve one technology enabling another technology as a tool, as a component, or as a model. The malleability and convergence of these developing technologies make revolutionary outcomes likely. Revolutionary outcomes make ethical considerations ever more important.

Better ethics

The number of ethical issues that arise tracks the development of a technological revolution. In the introduction stage there are few users and limited uses of the technology. This is not to suggest that no ethical problems occur, only that they are fewer in number. One of the important ethical issues during the introduction stage of the computer revolution was whether a central government data base for all United States citizens should be created. It would have made government more efficient in distributing services but would have made individual privacy more vulnerable. The decision was made not to create it. During the permeation stage of a technological revolution the number of users and uses grows. The technology is more integrated into society. More ethical issues should be expected. In the computer revolution there was an increasing number of personal computers and computer applications purchased. Indeed, because more people owned computers and could share files, ethical issues involving property and privacy were more numerous and acute. During the power stage many people use the technology. The technology has a significant social impact that leads to an increased number of ethical issues. During the power stage of the computer revolution the number of ethical issues has increased over the number in the permeation stage. Almost everyday papers report on new ethical problems or dilemmas created by computer technology. For example, identity theft by computer is more easily accomplished in today's highly networked world than it was in the days of free standing personal computers let alone in the days of isolated large mainframes. Or, as another example, in these days of the easily accessible and powerful web, the solicitation of children by child molesters has increased. In light of this conjecture about the relationship between the stages of a technological revolution and the increase of ethical problems I will propose the following hypothesis:

> Moor's Law: As technological revolutions increase their social impact, ethical problems increase.

This phenomenon happens not simply because an increasing number of people are affected by the technology but because inevitably revolutionary technology will provide numerous novel opportunities for action for which well thought out ethical policies will not have been developed.

From the computer/information revolution alone we can expect an increase in ethical problems. But other major technologies are afoot that have the promise to be revolutionary on the model of an open revolution. Although genetic technology, nanotechnology, and neurotechnology are not yet fully developed in this regard, they have two features that suggest that such development is likely. First, each is driven by a conception of a general capability of the field, a malleability. Just as computing is based on logic malleability, genetic technology is based on life malleability, nanotechnology is based on material malleability, and neurotechnology is based on mental malleability. They offer us the capabilites of building new bodies, new environments, and even new minds. Such fundamental capabilities are very likely to be funded, to be developed, and to have significant social impact. Second, the emerging technologies are converging. They enable each other as tools, as components, and as models. This convergence will move all these technologies forward in a revolutionary path. Thus, we can expect an increase in ethical issues in the future as the technologies mature.

The ethical issues that we will confront will not only come in increasing numbers but will come packaged in terms of complex technology. Such ethical issues will require considerable effort to be understood as well as a considerable effort to formulate and justify good ethical policies. This will not be ethics as usual. People who both understand the technologies and are knowledgeable about ethics are in short supply just as the need is expanding.

Consider too that many of the emerging technologies not only affect the social world but affect us as functioning individuals. We normally think of technology as providing a set of tools for doing things in the world. But with these potentially revolutionary technologies we ourselves will be changed. Computer chips and nanostructures implanted in us along with genetic and neurological alterations will make us different creatures, creatures that may understand the world in new ways and perhaps analyze ethical issues differently.

Assuming that emerging technologies are destined to be revolutionary technologies and assuming that the ethical ramifications of this will be significant, what improvements could we make in our approach to ethics that would help us? Let me suggest three ways that would improve our ethical approach to technology. First, we need realistically take into account that ethics is an ongoing and dynamic enterprise. When new technologies appear, there is a commendable concern to do all of the ethics first. Or, as sometimes suggested, place a moratorium on technological development until ethics catches up.[6] Both of these approaches are better than saving ethics until the end after the damage is done. But both the ethics first and the moratorium approach have limitations. We can foresee only so far into the future even if we were to cease technological development. We cannot anticipate every ethical issue that will arise from the developing technology. Because of the limitations of human cognitive systems, our ethical understanding of developing technology will never be complete. Nevertheless, we can do much to unpack the potential consequences of new technology. We have to do as much as we can while realizing applied ethics is a dynamic enterprise that continually requires reassessment of the situation.[7] Like advice given to a driver in a foreign land, constant vigilance is the only sensible approach.

The second improvement that would make ethics better would be establishing better collaborations among ethicists, scientists, social scientists, and technologists. We need a multi-disciplinary approach.[8] Ethicists need to be informed about the nature of the technology and to press for an empirical basis for what is and what is not a likely consequence of its development and use. Scientists and technologists need to confront considerations raised by ethicists and social scientists, considerations that may affect aspects of the next grant application or risky technological development.

The third improvement that would make ethics better would be to develop more sophisticated ethical analyses. Ethical theories themselves are often simplistic and do not give much guidance to particular situations. Often the alternative is to do technological assessment in terms of cost/benefit analysis. This approach too easily invites evaluation in terms of money while ignoring or discounting moral values which are difficult to represent or translate into monetary terms.

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[6] Bill Joy, "Why the Future Doesn't Need Us," *Wired* 8.4 (2000).

[7] James H. Moor and John Weckert, "Nanoethics: Assessing the Nanoscale from an Ethical Point of View," *Discovering the Nanoscale*, eds. Davis Baird, Alfred Nordmann and Joachim Schummer (Amsterdam: IOS Press, 2004).

[8] Nicely elaborated in Philip Brey, "Method in Computer Ethics: Towards a Multi-Level Interdisciplinary Approach", *Ethics and Information Technology* 2.2 (2000).

At the very least we need to do more to be more proactive and less reactive in doing ethics. We need to learn about the technology as it is developing and to project and assess possible consequences of its various applications. Only if we see the potential revolutions coming, will we be motivated and prepared to decide which technologies to adopt and how to use them. Otherwise, we leave ourselves vulnerable to a tsunami of technological change.[9]

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[9] A version of this paper was given as the International Society of Ethics and Information Technology (INSEIT) presidential address at the 2005 Computer Ethics: Philosophical Enquiry (CEPE) Conference at the University of Twente. I am indebted to many for helpful comments and particularly to Philip Brey, Luciano Floridi, Herman Tavani, and John Weckert.