Governance challenges of technological systems convergence

Jim Whitman
Department of Peace Studies,
Bradford University
Bradford BD7 1DP
UK

Abstract

The convergence of several technological systems (especially nanotechnology, biotechnology, IT and robotics) has now been adopted as strategic goal by several countries, most notably the US; and by the European Union. The anticipated benefits and related fears of competitive disadvantage have brought together a wide range of interested parties, both governmental and non-governmental. In the rush to enter and/or dominate this arena, the benign promise of Converging Technologies (CT) are highlighted, while a range of risks and less welcome (if difficult to quantify) implications are at best understated. What, then, are the prospects for exercising governance over the technological systems we are busy creating - and the uses to which they might be put? Was Thomas Edison correct when he asserted that ‘What man's genius can create, man's character can control?’ What will it mean to speak of ‘global governance’ in a world in which the technological promise of CT has been fulfilled?

Introduction

In developed countries, the extent of industry and commerce and the nature of other forms of socio-economic and political organisation require the governance of scientific advances and their technological applications, for a very wide range of purposes. Even within single states, we are now familiar with the regulation and control of such processes and products for ‘security’ in the broadest sense. For example, the UK government's ‘Biotechnology Regulatory Atlas’ contains the following categories: intellectual property; health and safety at work; animal welfare; prevention of deliberate misuse; transport, import and export; medical and veterinary uses; environmental and chemical issues; and food and agriculture issues. (UK Biotechnology Atlas). Plainly, the malign possibilities of advanced technologies are not confined to national security in the sense of territorial integrity and the defence of the population. The negative effects of technologies, both substantiated and feared, are also highlighted in various expressions of popular resistance to their outcomes or products (Bauer, 1997); in forms of dependence that entail new kinds and degrees of vulnerability (Rochlin, 1997); and within the social sciences, in the ‘risk society’ literature (Beck, 1999; Hood et al, 2001; Hull et al, 2002).

The governance of technology has long extended beyond the borders of nation states – in our own time, most notably with respect to efforts to exercise control over the capacity to develop weapons of mass destruction. However, the interests involved in the control of science and technology, even within states, are not confined to matters of risk assessment and the drafting of regulatory controls; nor in international terms, to regime-building. There are two reasons for this.

The first is that our globalized condition compounds all of the darker possibilities of technological innovation and application, even as it intensifies incentive and impetus to their furtherance. In other words, interests often cut at least two ways, with different aspects of security being antagonistic, but not mutually exclusive; or judged to be costly or risky, but nevertheless important or worthwhile. So it is that the economic benefits that accrue to nations through connection to the global information infrastructure also open channels of unwelcome political dissent (Watts, 2004); and many forms of business, social, cultural and scientific exchange are enabled, but concerns about national security are also extended, ranging from ‘unclassified but sensitive’ research to information warfare (Jones et al, 2002; *Information Warfare Monitor*). Likewise, the existence of a global pharmaceutical industry rests on a vast and intricate network of highly transferable expertise and information – but this can and has been employed for military and terrorist purposes (National Research Council, 2004).

It is a commonplace observation to note that technology furthers globalisation - and in turn, that globalising dynamics of various kinds further propel the development, deployment and uses of new technologies. Of greater note is that over time, this spiral of developments has brought about an international arena in which states are not only sited at both ends of the cause-and-effect of globalizing dynamics, but are also caught up in nets of globalized relations, few of which are within their direct control, even on a multilateral basis. For example, the global airline industry is highly regulated both nationally and internationally, but the diffusion of the SARS virus in 2003 – a complex interaction of natural systems and technologically-assisted human systems – accompanied its normal functioning.

Second, powerful interests are not confined to states and state agencies: a wide variety of non-state actors make strenuous efforts to shape the regulatory environments that affect their interests. For example, considerable private interests continue to operate in the framing of intellectual copyright regulation at national and international levels (Drahos and Braithwaite, 2000). And although the relationship between states and private actors can be antagonistic (recall US government suits brought against IBM and more recently, Microsoft), the interests are often complementary, particularly in respect of securing mutually beneficial systemic stability. This is one of the meanings of the Davos gatherings.

In addition, although national and international legislation establishes necessary regulatory frameworks, a great deal of the controlling, steering and facilitation of human networks (both technological and technologically-assisted) is non-governmental (Braithwaite and Drahos, 2000). These combinations of non-state, non-authoritative actors, at various levels of economic and social organisation, have been termed ‘governance without government’ (Rosenau, 1992, p.7) and are widely regarded as integral to global governance – at least insofar as that term is employed to describe an aggregate or summative phenomenon. Another important aspect of the global governance literature as it has developed to date is devoted to the study of the exercise of regulatory and control systems over various sectoral activities (finance, trade, health) - matters that are global in extent or in their implications.

But do we, or can we have the global governance of any advanced technological system – say, of biotechnology - in either of these senses? That is, does the sum of national, international and informal regulatory mechanisms pertaining to the many scientific lines of research, commercial applications and other public and private ventures in this field combine to give us a comprehensive and effective global governance of biotechnology? Conversely, can we hope for an all-inclusive, top-down global governance, at least of the more worrisome and potentially dangerous misuses of biotechnology – even given the recent failure to agree a verification protocol for the Biological and Toxin Weapons Convention (Dando, 2002)?

This is not a heartening line of speculation not only because political differences and the competitive disposition of states make international regulations so difficult to agree and enact, but also because we cannot abstract the high-level and/or sectoral governances of any technology from the character of these systems once they have achieved wide diffusion and/or easy availability, or have been adopted or adapted for purposes unanticipated, or combine with other features of our natural and political environments in unwelcome ways. What is one to make of the news that synthetic biology – the engineering of new life forms – is not merely a scientific advance, but has also taken the form of new commercial ventures? (*Scientific American*, 2004; Synthetic Genomics, Inc.). It is unrealistic to suppose that such enterprises (commercial or otherwise) will remain an exclusive domain, that they will all be public and verifiable, or (as discussed below) that interested parties, including states, will disadvantage themselves on the basis of the precautionary principle. After all, there is no world shortage of scientific expertise or physical requisites for the manufacture of pernicious biological agents; and even on a matter as far-reaching as agreed national standards for the release of genetically engineered organisms into the environment, The European Commission '…[had] to refer France, Luxembourg, Belgium, Netherlands, Germany, Italy, Ireland, Greece, Spain, Austria and Finland to the European Court of Justice for failing to adopt and notify national legislation implementing an EU law on the deliberate release of genetically modified organisms (GMOs) into the environment' (European Union, 2003).

It is against this backdrop that an extraordinary convergence of technologies is now under way. The most significant non-scientific aspect of these developments is that the principal agents for framing and securing global governance arrangements – states - are themselves the principal proponents and facilitators of technological systems convergence. Past experience (with respect to biotechnology) and the publicly stated disposition of these key players makes it highly unlikely that that we will witness anything different in respect of their benefits/risks calculus, or their legislative and funding initiatives. This will place both states and peoples in environments in which nearly every aspect of security will be affected – and although proponents' use of the adjective 'transformative' in these contexts is resolutely positive, that same descriptor can as easily be applied to the more worrying possibilities and uncertainties. After briefly outlining technological systems convergence, the remainder of the paper will discuss the difficulties states have already begun to encounter in aligning the race to advance and benefit from technological systems convergence and their security interests. Some of these difficulties have already appeared as unwanted aspects of globalization; but some are likely to be as unprecedented as the promised benefits of technological synergy.

Outline of technological systems convergence

'Technological systems convergence' describes a combination of enabling scientific discoveries (genetics; nanoscience), techniques (informatics; gene splicing) and advances in allied tools (computing power; scanning tunnelling microscopes; robotics) which greatly accelerate both the basic sciences involved and their practical applications, across a breathtaking range of subjects, from human health to materials science. The use of massive computing power in the human genome project – and subsequently in other gene-sequencing ventures – was a clear indication of a trend that has now widened and gained considerable momentum. In 1998, Jeremy Rifkin argued that '[T]he genetic revolution and the computer revolution are just now coming together to form a scientific, technological, and commercial phalanx, a powerful new reality that is going to have a profound impact on our personal and collective lives in the coming decade' (Rifkin, 1998, p.xv). In the intervening years, as computing power and speed have vastly increased and as our knowledge of fundamental life processes has expanded, biology has grown ever closer to information science – hence the creation of 'new resource economies in bio-information' (Parry, 2004, p.7). Perhaps the most enabling of the sciences is nanoscience (Royal Society, 2004, p.5) which has both organic and inorganic applications. The potential of converging technologies (CT) in general, with nanotechnologies at their heart, is captured in NASA's embrace of its potential:

> [T]he full potential of nanotechnology for the systems NASA needs is in its association with biology. Nanotechnology will enable us to take the notion of "small but powerful" to its extreme limits, but biology will provide many of the paradigms and processes for doing so. Biology has inherent characteristics that enable us to build the systems we need: selectivity and sensitivity at a scale of a few atoms; ability of single units to massively reproduce with near-zero error rates; capability of self-assembly into highly complex systems; ability to adapt form and function to changing conditions; ability to detect damage and self repair; and ability to communicate among themselves. Biologically inspired sensors will be sensitive to a single photon. Data storage based on DNA will be a trillion times more dense than current media, and supercomputers modeled after the brain will use as little as a billionth of the power of existing designs. Biological concepts and nanotechnology will enable us to create both the "brains and the body" of future systems with the characteristics that we require. Together, nanotechnology, biology, and information technology form a powerful and intimate scientific and technological triad (National Science Foundation, 2002, pp.13-14).

Advances in nanoscience and nanotechnology are rapidly furthering the unification of domains – a profound convergence of our understanding of, and ability to manipulate at the most fundamental levels, the material constituents and processes of both inert substances and living things. Expressed succinctly, 'From the point of view of nanotechnology, what used to be separate domains of biomedicine, information technology, chemistry, photonics, electronics, robotics, and materials science come together in a single engineering paradigm' (Nordmann, 2004, p12). Also part of the convergence trend are the cognitive sciences - sometimes classed under 'technologies for improving human performance' - which range from the possibility of a startling range of implants to brain-machine interfaces and what has even been described as 'humane machines.'

The unification of domains now under way has been seized upon by advocates who regard it as a goal to be pursued actively, rather than an indirect outcome of further advances within and between all of the concerned sciences and technologies.
In the largest and most comprehensive US study of converging technological systems sponsored by the US National Science Foundation and the US Department of Commerce (hereafter NSF/DOC), one of the participants expressed the prospect in blunt form: 'If the Cognitive Scientists can think it, the Nano people can build it, the Bio people can implement it, and the IT people can monitor and control it.' (National Science Foundation, p.57). Even allowing for hype and exaggerated claims (Tourney, 2004), the range of impacts of these developments can scarcely be grasped.

There are already serious matters at hand, exerting considerable pressure on our existing systems of regulation and control. In biotechnology, for example, a synthetic polio virus was recently created in a laboratory from scratch (Orwant, 2002); and it is now possible to synthesise a virus in only two weeks (Págan, 2003). At the same time, a recent survey revealed that gene sequencing companies do not routinely screen their clients (Aldhous, 2005). In the filed of nanotechnology, even as investigations are under way into the environmental and health risks of nanoparticles, their commercial applications – from glass products to cosmetics – are already well established. Meanwhile, the military potential of nanoscience is a source of serious concern, here summarised in the 2004 study by the Royal Society on nanoscience and nanotechnology:

> Military developments raise several obvious social and ethical issues, most of them …not confined to nanotechnologies. Manipulation of biological and chemical agents using nanotechnologies could result in entirely new threats that might be hard to detect and counter. Some observers have suggested that refinements of both existing and new weapons systems, through applications of nanotechnologies, might lead to a new form of arms race. One can also ask whether the use of arms control frameworks developed for existing categories of nuclear, chemical and biological weapons will be sufficient to control future developments involving nanotechnologies (Royal Society, 2004, pp.55-6; Altmann, 2005).

But military nanotechnology is already well advanced. MIT's Institute for Soldier Nanotechnologies (MIT) has now received US$50 million of research funding from the US Army; and the US Department of Defence is a key funder of nanoscience research and development for military purposes. Other countries have already followed suit (Langley, 2005). There are in addition a panoply of other developments brought about by technological systems convergence, with novel, bewildering or disturbing implications – economic, social, legal and ethical.

It is difficult not to share some of the wonder and enthusiasm for matters as beneficent as the promise of greatly enhanced biomedicine, advanced prosthetics and other technologies for the disabled and for treating debilitating, chronic conditions. Much the same applies to fields such as materials science, environmental protection/restoration and technologies that will enhance public health and safety. Of course, both public and private actors are also enthusiastic about the possibilities of national competitive advantage – and of wealth creation, a pattern already established in the life sciences, not least in respect of biology-as-information: gene patenting (Stenson and Gray, 1999). It is reasonable to expect governments to play an active role, if not a leading one, in matters as far-reaching as these. Yet a sense of due caution and an awareness of the range of dangers and uncertainties is not always present (or given more than rhetorical acknowledgement) in most of the public or private pronouncements on technological systems convergence. The primary European Union document on this theme (Nordmann, 2004) does at least commence with a sober reflection: 'Each [of the likely characteristics of CT applications] presents an opportunity to solve societal problems, to benefit individuals, and to generate wealth. Each of these also poses threats to culture and tradition, to human integrity and autonomy, perhaps to political and economic stability'(*Ibid*, p.3). At the national level in the US, however, official support for CT, in both political and practical terms, is much less cautious and is likely to set the pace for the rest of the world, whether for collaboration or competition.

The drive toward technological systems convergence

In 2002, the US National Science Foundation and the US Department of Commerce sponsored a large, comprehensive report entitled, 'Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science' (National Science Foundation, 2002). The report is distinctive in terms of its length, thematic inclusiveness and detail, but not in respect of other national drives to further CT in their own domains, or to establish a presence in what is probably the key CT endeavour – nanoscience (*Science in Africa*; Varga, 2004). Nevertheless, the NSF/DOC document evinces a high degree of political support for CT; stresses the importance of public and private funding; and expresses a keen recognition of the national and commercial advantage to be had by entering the field early and securing a commanding position. The potential uncertainties and dangers are only given outline recognition, as are the considerable regulatory challenges.

There is also no shortage of ideology in the report, together with argumentative flaws which, whether or not they overstate the promise, certainly misrepresent the ways in which technologies can contribute to human betterment – and partly as a consequence, underestimate the extent to which CT might quickly surpass our national and international means of governance. The following (in italics) are indicative:

- *Science and technology will increasingly dominate the world, as population, resource exploitation, and potential social conflict grow. Therefore, the success of this convergent technologies priority area is essential for the future of humanity* (National Science Foundation, p.xiii).

This is a confused and confusing assertion. One is apparently meant to understand that social and environmental stresses are worsening in parallel with the advance of science - without the suggestion that there is any causal relationship between them, even though science and technology currently 'dominate' the world in ways unspecified. Clearly, ‘therefore’ does not follow, unless one anticipates convergence as a kind of *deus ex machina*.

- *Unification of science based on unity in nature and its holistic investigation will lead to technological convergence and a more efficient societal structure for reaching human goals* (*Ibid*, p.1).

What is implicit here is that ‘human goals’ will be convergent in much the same way that the authors predict that various sciences will be. It is by no means clear that the array of possible applications of CT will make societies, within or between states, more coherent internally, or more congruent in terms of desirable outcomes. One need only look at the divergence is social attitudes toward genetically-modified food between Europe and North America so see the kinds of difference and difficulties that might be brewing.

- *Technological convergence may be the best hope for the preservation of the natural environment, because it integrates humanity with nature across the widest range of endeavours, based on systematic knowledge for wise stewardship of the planet* (*Ibid*, p.9).

This is an utterly remarkable assertion. The preservation of the environment is fundamentally a mater of human relations, not technology. Humanity is already integrated with nature: this is fundamental to any understanding of life and life processes, together with a rudimentary understanding of open, complex systems (Vickers, 1983). Humanity is integrated with nature across the full range of human endeavours: this is one of the meanings of environmental degradation through the accumulation of countless mundane human acts (car driving, home heating, jet travel). There is nothing in any body of systematic knowledge that immediately or necessarily opens out on wisdom: our systematic knowledge of biology can be turned to finding a cure for HIV/AIDS, or to making biological weapons. Wisdom does not inhere in data bases or scientific textbooks. In addition, the idea of human ‘stewardship’ of the planet might be attractive, but it is a contestable notion. And ‘wise stewardship’ – or whatever passes for it – is not going to take place outside of a political arena. That is why, despite the extent of the scientific evidence demonstrating climate change, the international politics around the topic remain quite contentious.

Former US House of Representatives Speaker Newt Gingrich is of course ideologically partisan, but his views on the way in which CT might alter the relationship between citizen and government -–and the role of government itself – is not out of place in the context of the thoroughgoing review of CT in which it appears:

- *Eventually a political movement will develop a program of change for government that will provide greater goods and services at lower and lower costs. When that movement can explain its new solutions in the language of everyday life, it will gain a decisive majority as people opt for better lives through better solutions by bringing government into conformity with the entrepreneurial systems they are experiencing in the private sector* (National Science Foundation, *op cit*, p.40).

And who needs politics?

- *The more Americans focus on the common sense and the cooperative effort required for their own lives, and the more they focus on the excitement and the wealth-creating and opportunity-creating nature of the entrepreneurial world, the more they reject politics and government as an area of useful interest* (*Ibid*, p.45).

It would be mistaken to dismiss this, not least because it is compatible with characterisations of the 'governance without government' phenomenon that is at the heart of theorising about global governance:

> [S]ystems of rule can be maintained and their controls successfully and consistently exerted even in the absence of established legal or political authority. The evolution of intersubjective consensuses based on shared fates and common histories, the possession of information and knowledge, the pressure of active or mobilizeable publics, and/or the use of careful planning, good timing, clever manipulation and hard bargaining can - either separately or in combination - foster control mechanisms that sustain governance without government (Rosenau, 1995, p.15).

The main deficiency of the CT debate as it has developed so far is that it ranges across so many areas of human endeavour and organisation, with such a profusion of practical and ethical implications, that questions of governance have been obscured – if not supplanted. Yet security concerns – even of a familiar 'national security' cast - are clearly indicated in converging technologies. (An entire sub-section of the NSF/DOC study is devoted to national security; and the US Department of Defence has designated nanoscience as a strategic research area (Murday, 2003)). Although much of the military research and development is still in its early stages and is likely to entail long lead-times before deployment, the kinds of prohibitive and regulatory mechanisms needed to prevent nanoscience-assisted arms races, to stop the spread of such technologies to unstable regimes or malign non-state actors and to forestall other forms of technically-driven forms of international insecurity also require a great deal of time and painstaking effort – which is thus far absent from the field of nanotechnology.

Yet what appears to be a national effort to 'outrun' security and other political problems arising from new technologies is not a CT novelty. We are already familiar with the growing gap between the speed of scientific advance in biotechnology and the possibilities this opens up for pernicious applications – and commensurate arms control treaties and other forms of governance (Dando, 2004; Wheelis and Dando, 2005). Similarly, research is beginning to indicate that the products of nanotechnology might in fact be serious pollutants, even as it attracts considerable investment from both the public purse and from private investors. The Royal Society report (above) notes that 'There is virtually no information available about the effect of nanoparticles on species other than humans or about how they behave in air, water or soil, or about their ability to accumulate in food chains' (Royal Society, *op cit*, p.x). Yet its summary conclusions contain the following: 'The evidence suggests that at present, regulatory frameworks at EU and UK levels are sufficiently broad and flexible to handle nanotechnologies at their current stage of development' (*Ibid*, p.11). This is a striking conclusion, particularly when one considers the numerous questions that have been raised over the environmental impacts of 145 million acres of genetically modified crops (Barnett, 2000; Brown, 2002).

Unfortunately, public policy tangles of this character and of these dimensions – involving the application and dissemination of technology under highly globalized conditions – and entailing hugely complex, often unanticipated interactions of human and natural systems – are now a familiar feature of our globalized world (Whitman, 2005b). The introduction of the new technologies arising from convergence will certainly not surmount them, at least not by dint of their technical properties alone. It is not difficult to predict that we will experience problems similar in outline, if different in configuration (and possibly, severity) as the enthusiastic pursuit of CT continues apace. The reasons are summarised under four thematic points below. The central difficulty is that the promise of security in one realm cannot be insulated from a host of other, unwanted security implications in other realms, arising from the same technological applications.

1. The problem of isolating and sequencing security priorities

The convergence of scientific and technological domains holds little prospect for simplifying any aspect of public policy-making, let alone the governance of those systems themselves. The revolution in the biological sciences has already made this clear, for while the promise of breakthroughs in pharmaceutical, medical, agricultural and other fields are considerable, we must already deal with a host of non-productive and worrying consequences that arise from the same sources - not least the availability in the open scientific literature of genomic information that can be turned to malign use (National Research Council, 2004; Zillinskas and Tucker, 2005). Indeed, in an unclassified summary report, ‘The Darker Bioweapons Future’, the US Central Intelligence Agency argued:

> The genomic revolution is pushing biotechnology into an explosive growth phase. […] [T]he resulting wave front of knowledge will evolve rapidly and be so broad, complex, and widely available to the public that traditional means for monitoring Weapons of Mass Destruction development could prove inadequate to deal with the threat from these advanced weapons (Central Intelligence Agency, 2003).

The report makes plain that the governance challenges in this field alone will engender a host of other, very serious intelligence and security issues:

> Detection of related activities, particularly the development of novel bioengineered pathogens, will depend increasingly on more specific human intelligence and […] will necessitate a closer – and perhaps qualitatively different – working relationship between the intelligence and biological sciences communities.

As technological systems convergence accelerates, these kinds of developments are not confined to biotechnology. As the NSF/DOC study acknowledges, ‘Clearly, the ability to build highly intelligent machine systems will have profound implications – in four important areas in particular: science, economic prosperity, military power and human well-being…’ (National Science Foundation, *op cit*, p.286). It is already discernible that although government-supported drives for CT-enabled economic competitive edge and for military applications are likely to be at odds with caution and with restrictive governance regimes (both national and multilateral), governance issues will eventually manifest themselves – and very probably in forms even less tractable than the governance of the technologies themselves.

The prospect of enormous gains – (national security, wealth creation and 'human performance' all figure prominently) – also engenders calculation and fears of a strikingly Realist cast. In the following quote, the Foresight Institute (whose mission is to 'ensure the beneficial implementation of nanotechnology'**)** advances the classic Realist 'security dilemma':

> It is worth considering the possibility of simply banning nanotechnology altogether, in which case we would avoid the need to expend further effort on technology policy questions. There will be enormous pressures to develop nanotechnology because of the potential benefits to society, as well as the threat of others gaining military superiority should they develop it first. It does not seem likely that *all* nations would agree to ban development. Even if they did, verification would be nearly impossible because research efforts could be easily hidden in small laboratories. And because of the mutli-disciplinary nature of nanotechnology, one would have to ban a large fraction of scientific research because so many areas will impact on developing nanotechnology, e.g.- scanning tunneling microscopes or computational chemistry. So it seems unlikely that we could implement a verifiable worldwide ban (Forrest, 1989).

The author continues:

> 'If we tried to block or slow the development of nanotechnology in the United States, or in other democracies, we would increase the chances that nanotechnology is first developed in a country without a free press. In which case we could not be certain that that country would not use nanotechnology to oppress its neighbours or the rest of the world. So efforts to slow progress only serve to threaten our freedom.'

Similarly – whatever one makes of the reasoning – the NSF/DOC document contains the following assertion: 'If we want this economy to grow, we have to be the leading scientific country in the world. If we want to be physically safe for the next years, we have to be the leading scientific country in the world. If we want to be healthy as we age, we have to be the leading scientific country in the world. It would be literally madness to offer anything except an increase in scientific funding' (National Science Foundation, *op cit*, p.40).

The governance of technological systems is not a lost hope, but the current climate suggests that the powerful interests promoting and furthering it will hardly be inclined to prioritise either highly restrictive or cautious approaches. And as Susan Wright has illustrated with respect to the development of genetic engineering in the formative decade 1972-82, formal governance frameworks can be used to accommodate private interests:

> …[T]he Reagan administration established the Biotechnology Science Coordinating Committee (BSCC), a high-level interagency body under the White House Office of Science and Technology Policy, to coordinate existing

> controls for plants, animals, and microbes. Formally charged with sharing scientific information and coordinating and guiding regulatory policy for genetic engineering, the BSCC sought informally to realize the role ascribed to it by one government official, to 'unshackle industry in pursuit of biotechnology' by encouraging agencies to limit the scope of rule making under their statutes (Wright, 1994, p.441).

The problem of separating and balancing risks and benefits arising from the embeddedness of technological systems

The European Commission's report on converging technologies notes that that they '…will form an invisible technical infrastructure for human action. – analogous to the visible infrastructure provided by buildings and cities. The better they work, the less we will notice our dependence on them or even their presence' (Nordmann, *op cit*, p. 3). But technological ubiquity creates pervasive vulnerabilities – as our reliance on computers and computer-assisted systems demonstrates, characterised in the following as a 'computer trap':

> …the elaborate, long-term, collective effects of the possibly irreversible and largely unexamined drive to computerize and network everything and anything whose efficiency or economic performance might thereby be improved. In the process, those who re-design and re-engineer the large-scale social and socio-technical systems that are essential for managing the complexities and structures of modern life seem to have little understanding of the potential vulnerabilities they are creating. Such effects are already being noted in the similar, persistent search to eliminate from hazardous systems all possible sources and causes of 'human error.' Whether those systems be military or industrial, financial or bureaucratic, the increased tightness of coupling, lack of redundancy, and speed of response, will make human intervention or control difficult at best when (and not if) something goes wrong - particularly for those systems whose means and mechanisms of operation are so deeply embedded in the computers that operate them that no human being fully understands them (Rochlin, *op cit*, p.21).

Recently, one young computer hacker inadvertently shut down the port of Houston; another hacked into almost 100 networks operated by the U.S. Army, Navy, Air Force and the Pentagon, which cost $1 million to rectify. And at a deeper level, the complex networking of existing technological systems creates unanticipated and unpredictable systems behaviours:

> Just as they did after major blackouts in the Northeast [US] in 1959, 1961, 1965 and 1977, investigators are trying to figure out exactly what set off the avalanche of failure [in August 2003]. ….But what all the failures had in common is that the grid – complicated beyond full understanding, even by experts – lives and occasionally dies by its own mysterious rules. …The incomprehensible complexity of the grid comes with its own irreducible pathologies, experts say. The system brings power to every wall in the United States, but increasingly, as the scale of the grid grows, it can suddenly take away that power. And given the sensitivity of the grid to accidental power failures, the realization of what deliberate acts of terrorism could do is also raising new concerns (Glanz, 2003).

New technologies – pervasive, embedded and intricately networked – can only add to the complexity of our highly engineered living and working environments, already moving outside of ready comprehension. Yet the benefits of computing are obvious – and widely shared. Nevertheless, we have no reason to suppose that the benefits/drawbacks ratio will remain constant against a huge increase in the number, speed and functions of future generations of computers – and other technological systems with which they will be closely integrated - as they become further integrated into our lives.

Public deliberation versus the speed and application of discoveries, fuelled by powerful interests

Already, the volumes and speed of electronic financial transaction exceed the human capacity to comprehend them. These data flows are not peripheral – they are systemic. Whatever might count as the global governance of international finance must deal with this data belatedly. Technological systems convergence will, of course, vastly expand this kind of impediment to timely comprehension (and by extension, governance). It might suffice to note that in 1998, a single pharmaceutical company synthesised 1.67 million compounds in a two-week period (Parry, *op cit*, p.49).

Quite aside from difficulties of timely and detailed comprehension, the strain placed on our deliberative and predictive capacities by the speed and significance of recent developments is a clear indicator of the crises of governance we are likely to face in the wake of technological systems convergence. This is perhaps most clear in one long-established regulatory area: the scrutiny of patent applications. 'In 1999 alone, 289,448 patent applications were filed in […] bioinformatics[s] and the United States Patent and Trademark Office (USPTO) has created working groups to deal with the influx of bioinformatics applications' (Chow and Fernandez, 2001). Subsequently, in a surprising twist on 'convergence', patent attorneys have been advised by the USPTO that 'Applicants should be increasingly aware of overlapping biotech and computer technologies. To the extent that an invention overlaps into the computer arts, biotech attorn[ies] should become familiar with the Examination Guidelines for Computer-Related Inventions' (Woodward).

And although both the primary American and European Union documentation on CT acknowledge the likelihood of legal and ethical 'challenges', it is not at all clear that the public policy machinery of any state is capable of keeping pace with scientific and technological developments that can so quickly find expression in products and processes, or which might entail protracted and detailed international negotiation. One might also consider that currently, scientific advances impacting on human embryology and stem cell research have created serious, protracted debate of a depth and seriousness that cannot be quickly resolved by resort to factual matters, or appeals to a particular conception of the national interest. The NSF/DOC document acknowledges that 'There must be a free and rational debate about the ethical and social aspects of potential uses of technology, and government must provide an arena for these debates that is most conducive to results that benefit humans' - an unobjectionable if highly ambiguous goal. It then goes on, 'At the same time, government must ensure economic conditions that facilitate the rapid invention and deployment of beneficial technologies, thereby encouraging entrepreneurs and venture capitalists to promote innovation' (National Science Foundation, *op cit*, p.30). The combination of intense interests and felt pressures building up around converging technologies is evident in this passage, but most pressured of all will be the kinds of slow-moving, inclusive, reflective and deliberative processes by which societies maintain their values in the face of rapid change. This is doubtless what Thomas Edison took for granted when he confidently asserted, 'What man's genius can create, man's character can control'- but not, we might now acknowledge, under any circumstances.

The problem of initiating governance over systems that are widely disseminated and/or easily accessible.

Extensive and effective disseminative systems
Widely distributed human systems are *disseminative* to the extent that they 'facilitate very considerable interaction and exchange, both within and between human and natural systems' (Whitman, 2005a, p.87) It is disseminative systems that facilitate the adaptations of new technologies for the full range of human purposes, for good and for ill; and they also engender exchanges between human and natural systems. The world wide web can and does accommodate both legitimate money exchange and money laundering; the world's airline industries carry both licit and illicit goods; and they are capable of moving large numbers of people and of conveying disease agents around the planet. We can work to mitigate some of the negative possibilities, but we cannot choose to exclude them, without disabling the routine functioning of the disseminative systems themselves.

World-wide dissemination of expert knowledge; and easy availability of raw materials and research/production requisites
Scientific research, global industries and the world-wide network of higher education institutions are all linked through the global communications infrastructure. However, as the capacity to engage in serious misuse of technologies reaches beyond sanctioned and/or regulated agents; and as 'leading edge' knowledge becomes readily accessible and comprehensible, the routine exchange of scientific findings can engender security risks of a high order. Again, no one wants to disable such important and ordinarily valuable systems, but nor do we want to assist terrorist interest in the genetic manipulation of pathogens, especially since the physical requirements are not difficult to secure. In 1999, US government agents were able to assemble a small laboratory from commercially available equipment, from which they manufactured two pounds of anthrax simulants, without raising any attention from the security services (Miller, et al, 2001).

The systems they comprise, or of which they are a part, are open systems
However much they develop and converge, technological systems both old and new are open systems:

> Open systems depend on and contribute to their surround and are thus involved in interdependence with it as well as being dependent on the interaction of internal relationships. This interdependence imposes constraints on all their constituents. Organization can mitigate but not remove these constraints which tend to become more demanding and sometimes even more

> contradictory as the scale of organization rises. This places a limit, though usually not a predictable one, on the possibilities of organization (Vickers, *op cit*, p.17).

This insight should dampen some of the more encompassing, over-arching hopes expressed by proponents of CT. 'New professions for humans and new roles for machines may arise to mediate between all this complexity and the individual person,' we are told. 'It may be possible to develop a predictive science of society and to apply advanced corrective actions, based on the convergence ideas of NBIC [nano-bio-information-cognitive technologies]. Human culture and human psychology may undergo rapid evolution, intertwining like the twin strands of DNA, hopefully guided by analytic science as well as traditional wisdom' (National Science Foundation, *op cit*, p.23). In essence, this is the hope for a technological fix for the human condition. But technological innovations only find meaning and use as elements in human systems; and security - for individuals, societies and nations - is a relational quality, not a technical one.

Conclusion

A large part of the drive to further the advancement of CT is positive, notwithstanding the kinds of gold rush mentality that also accompanied the advent of biotechnology. Yet the available prognostications and public pronouncements reveal an underlying anxiety, most notably in concerns about national economic, industrial and scientific competitive edge. Philip J. Bond, Undersecretary for Technology at the US Department of Commerce argues, 'Look all around the globe at the work that's going on at the nanoscale. American leadership is at stake, but we need a global framework for going forward' (*ibid*, p. 35). Likewise, the following:

> Technological superiority is the fundamental basis of the economic prosperity and national security of the United States, and continued progress in NBIC technologies is an essential component for government agencies to accomplish their designated missions. Science and engineering must offer society visions of what is possible to achieve through interdisciplinary research projects designed to promote technological convergence' (*Ibid*, p.14).

Although 'national security' is routinely a free-standing thematic consideration in CT studies and pronouncements, the widest meaning and implications of the term are also implicit elsewhere; and although at present this current has a largely American cast, other states are likely to be affected, in ways which bear an inexact but nevertheless striking parallel to the national security mentality that fuelled the Cold War. Then, 'national security' was less a doctrine than a seemingly paradoxical condition which became embedded in the foreign policy outlook of successive U.S. administrations: it is that the conditions which fostered the country's economic prosperity, military capability and political initiative in the postwar era, simultaneously suggested a range of threats and a degree of vulnerability which appeared all the more precipitous because of the heights of American wealth, power and influence (Yergin, 1977).

In our own time, scientific advances and their technological applications, once the tools of a security calculus, are increasingly becoming security arenas unto themselves. This kind of convergence, abetted by private interests, political ambition and fear, has now found expression (again, in the NSF/DOC report) in a policy orientation that would have amazed and appalled Edison:

> It may be possible to influence the ways convergent technologies will change economics and society, on a national scale, by providing leadership and support for a nationwide, collaborative development effort. […] This effort should have many stakeholders in education, healthcare, pharmaceuticals, social science, the military, the economy and the business sector to name a few (National Science Foundation, *op cit*, p.3).

That we might be able to *influence* the transformation of the human condition as a consequence of our conscious actions and defaults is a subordination of human purpose to human circumstance as pervasive and radical as any in history.

More immediately, our current disposition militates against the kinds of thinking necessary for conceiving national and international governance initiatives. Converging technologies are being developed and introduced into a world that is already intensively globalized, highly engineered, systems rich, environmentally stressed and politically fragmented. But what we are up against immediately is a 'do or die' mentality: 'Progress [in CT] can become self-catalyzing if we press ahead aggressively; but if we hesitate, the barriers to progress may crystalize and become harder to surmount' (National Science Foundation, *op cit*, p.3). The time available to us to think constructively about the governance of converging technologies will in all probability be short, since our deliberative capacities are already being outpaced by scientific advance, especially in the field of biotechnology; and because entrenched political and economic interests militate against strict regulatory and control regimes. The alternative, easily reached by default, is forms of response to globalized systems that are outside the authoritative control of any single state; and belated, high-stakes political and diplomatic efforts to halt the movement in unwelcome directions of developments we ourselves have set in train. The 2003 war against Iraq – ostensibly to prevent its programme of weapons of mass destruction – should give us pause.

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