Why Converging Technologies Need International Regulation

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Abstract

Emerging technologies such as artificial intelligence, gene editing, nanotechnology, neurotechnology and robotics, which were originally unrelated or separated, are becoming more closely integrated. Consequently, the boundaries between the physical-biological and the cyber-digital worlds are no longer well defined. We argue that this technological convergence has fundamental implications for individuals and societies. Conventional domain-specific governance mechanisms have become ineffective. In this paper we provide an overview of the ethical, societal and policy challenges of technological convergence and propose a governance framework based on participatory governance and the protection of the most vulnerable.

Introduction

What are converging technologies?

Since the beginning of the 21st century, the increasing interconnectivity of computing systems and networks combined with the rise of intelligent automation have exerted a rapid change in technology, industries, as well as societal patterns and processes. Concurrently, the embedding of sensor and computing capabilities into everyday objects (a phenomenon known as the *Internet of Things* or *IoT)*[1] and living organisms (*Internet of Bodies*)[2], as well as the increasing reliance on computational modelling in nearly any field of human activity, have blurred the lines between the physical, digital, and biological worlds.

As a consequence of that, once unrelated technologies such as digital computers, sensorics, artificial intelligence (AI), gene editing, neurotechnology, medical prosthetics, and nanomaterials have become increasingly inter-dependent and applicable across multiple domains. For example, AI algorithms and computational models have become essential tools for scientific research and innovation in nearly any field of knowledge production and technology development, from medicine to banking, from transportation to scientific discovery. Further, medical technologies are increasingly equipped with sensor technologies and computing capabilities, making it possible to collect and share vast troves of biometric, physiological and behavioral data either invasively (through medical implants and swallable technologies) or non-invasively (via wearables and smartphone-based applications). This close proximity and functional integration between the human body and digital technologies can be referred to as a cyber-physical system (CPS), which is an integrated system consisting of both cybernetic and physical-biological components.

Hence, "technological convergence"[3] means a new socio-bio-technical phenomenon involving:

A. the increasing ubiquity and pervasive distribution of computing capabilities across both physical objects and biological organisms;
B. the erosion of a clear separation between the physical, digital, and biological domains due to emerging technologies such as artificial intelligence (AI), gene editing, nanotechnology, neurotechnology and robotics;

C. the increasingly frequent co-occurrence of the technologies listed above and their large-scale spreading in ways that may be hard to detect, protect from, and manage.

Converging technologies are a multidisciplinary enterprise. As a NSF/DOC-sponsored report put it: "If the Cognitive Scientist can think it, the Nano people can build it, the Bio people can implement it, and the IT people can monitor and control it”.[4] According to the World Economic Forum [O], for example, "[w]e’re entering the era of the "Internet of Bodies" [IOB]“ which makes it possible to „collect our physical data via a range of devices that can be implanted, swallowed or worn“.

While a closer integration between formerly unrelated technologies promises significant contributions to socio-bio-technical innovation and human well-being, it also raises critical challenges for ethics and governance. Due to their potential for social disruption, the socio-bio-technical phenomena described above have been often been referred to as "the fourth industrial revolution". This label reflects the rapid societal transformation elicited by converging technologies and resulting in pervasive automation, interconnectedness and data exchange in technologies and processes that include CPSs.

What can converging technology do?

The increasing minitiaturization of sensor technology has made it possible to embed sensing capabilities into everyday objects and, more recently, even human bodies. For example, Digital Pills (DP) are an innovative drug-device technology that permits to combine traditional medications with a monitoring system that automatically records data about medication adherence as well as patients’ physiological data[5]. In the future, sensor technology is expected to reach nano scale, which implies components sized from 1 to 100 nanometers [6]. This will enable novel opportunities for physiological monitoring of the human body as well as novel medical and extramedical technological solutions based on nanoelectronics and biomaterials.

In this connection, magnetite particles[7] and graphene-based nanoparticles[8] have been explored as substances of interest for interfacing with human cells including neurons, a process sometimes referred to through the labels "smart dust" or "neural dust"[9] [10]. Self-replicating particles have also shown potential. For example, research at the interplay of genetic engineering and optogenetics has also shown that engineered light-switchable RNA-binding proteins allow for optogenetic control of ribonucleic acid (RNA) function and metabolism[11]. Furthermore, directed energy technologies might make it possible to read out distributions and movement patterns of nanoparticles by refraction or diffraction, thereby revealing microstructures and activity patterns of organic matter, including bodily organs[12]. On the long term, similar approaches may be used to detect diseases more promptly and even remotely[13].

CPSs are intended to deliver massive amounts of detailed data for personalized treatments in the area known as precision medicine[14] [15]. The aim is to create highly accurate pictures of our bodies and minds, called "digital twins"[16]. In the field of neurotechnology, the miniaturization of electrodes[17] together with rapid advances in AI for brain data analysis[18] is radically improving both retrospective and predictive brain activity mapping and analysis. On the long term, similar models could be applied to the semantic decoding or manipulation of mental states[19] [20].

The application of converging technologies is not restricted to reading data about human physiology and behavior, but also to leveraging such information for the pursuit of physiological, psychological and behavioral change. Applications may range from healing diseases such as cancer[21], mitigating the cognitive or affective symptoms of some psychiatric disorders or eliciting behavioral change among people with eating disorders such as anorexia nervosa or traumatic disorders such as PTSD. For example, the miniaturization of robotics platforms has led to numerous microrobot and nanorobot application that leverage precision medicine[22]. Similarly, neurotechnologies such as deep-brain stimulation (DBS) and transcranial magnetic stimulation (TMS) are being used to mitigate the tremor symptoms of Parkinson's disease and the mood imbalances caused by major depressive disorder[23 24].

In the future, behavioral change programs may be applied not only to people with psycho-behavioral disorders, but also to healthy subjects, which raises substantive ethical questions. For example, the use of converging technologies for the purpose of human sensory and cognitive augmentation [25], i.e. the targeted upgrading of human sensory and cognitive capacities, is being pursued with the ultimate goal of transcending natural human abilities, hence forging transhumanism[26].

Note that many of the afore-described use cases are still in the development stage, hence they will have to pass various feasibility and quality checks and overcome translational barriers in the future.

The dual-use problem of converging technologies

While creating ample opportunities for improving health, extending human abilities, and expanding life spans, converging technologies also create opportunities for dual-use. As defined by the European Commission, dual-use items are goods, software and technology that can be used for both, civilian and military applications. They may pose threats to public health, individual safety, or national security. In more general terms, dual-use can also refer to any technology, which can satisfy more than one goal at any given time, including both benevolent and nefarious goals. For instance, state actors may coopt converging technologies with the purpose of implementing novel forms of behavioral surveillance and control. By gaining access to data from technologies such as consumer neurodevices or sexual health apps, for instance, state actors may surveil highly sensitive information such as mental and reproductive information. Similarly, the availability of such novel and continuous data sources may be utilized to achieve more advanced forms of *profiling, social scoring and targeting*. While this risk applies to any state actor, technologically advanced autocratic countries are particularly at risk of establishing some form of *technological totalitarianism*. Finally, state actors may utilize converging technologies for non-peaceful aims, particularly in the context of *hybrid wars*[27] (see Table 1).

Non-state actors are also likely to engage in the intentional repurposing of converging technologies for non-benign aims. For example, as computing capabilities are increasingly embedded in biological systems such as human bodies, biology becomes subject to the same vulnerabilities as information technologies. These include the risk of malicious hacking, unauthorized data extraction, digital manipulation etc. The malicious hacking of fundamental bodily or mental processes will likely pose novel threats in the coming decades. Malevolent individuals or organized criminal groups are likely to exploit these vulnerabilities in manners analogous to current forms of *cybercrime and cyberterrorism*. This may also involve new opportunities for mis- and disinformation, psyops, censorship, cybermobbing, psychological harassment, insider jobs, and other crimes.

While the dual-use problem is inherent in any technology, the dual-use challenges raised by converging technologies are novel from a variety of perspectives.

First, converging technologies such as digital pills and nanobots may enable not only exogenous surveillance (i.e., the *trac(k)ing of people* everywhere), but also endogenous or *in-body surveillance*. Second, converging technologies such as affective computing, immersive environments and neurotechnology may enable novel forms of *mental surveillance and control*, as they may enable more direct and predictively accurate processing of mental information such as information about cognitive and affective states. Third, as mentioned earlier, converging technologies that enable CPSs expose biophysical systems (including living organisms) to the same risks and vulnerabilities of computer systems. Fourth, technologies that manipulate matter at the micro- and nano-scale are likely to be harder to detect and monitor. Hence, it is expected to be more difficult to prevent their cooptation for nefarious aims by state or non-state actors, e.g., their exportation as dual-use goods. In particular, those operating at the quantum scale may display quantum mechanical effects, hence exhibit special properties of matter, which occur below a given size threshold. It is unlikely that current safety safeguards are well-equipped to address those effects and properties.

Even more fundamentally, converging technologies urge a foundational conceptual transformation of the notion of dual-use. Conventional dual-use problems involve the risk that a certain technology developed for a certain purpose and in a certain area (e.g., the civilian domain) is coopted for a different purpose and applied to a different area (e.g., the military domain). These conventional dual-use problems may be mitigated through expert control policies such as those elaborated by the Swiss State Secretariat for Economic Affairs[1] and the export control system of the European Commission[2]. These policies typically involve the creation of common lists of dual-use items, common export control rules and compliance measures for exporters and brokers, as well as other rules aimed at mitigating the proliferation of weapons derived from non-military technologies. However, with the advent of converging technologies it is very difficult, if not conceptually impossible, to limit cross-domain export. The reason for that stems from the fact that that converging technology is inherently cross-domain, hence immune to sectorial controls.

Recent failures in international governance, such as the United Nations‘ inability to establish a ban of autonomous weapons[28] indicate the difficulty of governing converging technologies. The dual-use potential of neuro- and nanotechnology may pose even greater challenges than killer robots and drones. In an increasingly politically polarized and so-called over-populated world, the dual-use of converging technologies may generate novel threats to life and health for everyone. It should also be noted that the frequency and severity of threats is likely to increase with the increasing power and pervasiveness of converging technology applications.

Table 1- Some dual-use risks of converging technologies

Risk	Converging technologies that might enable it
Novel forms of behavioral surveillance and control (e.g. in-body), technological totalitarianism	Digital pills, wearables, neurotechnology, microelectronics, affective computing
New kinds of profiling, scoring, and targeting	DTC genetic tests, digital pills, wearables, neurotechnology, neuroelectronics, emotion AI
New forms of hacking, cybercrime, and privacy threats	Emotion AI, neurotechnology, personal reproductive technologies

[1] See: https://www.seco.admin.ch/seco/en/home/Aussenwirtschaftspolitik_Wirtschaftliche_Zusammenarbeit/Wirtschaftsbeziehungen/exportkontrollen-und-sanktionen/exportkontrollpolitik.html (last retrieved: August 7, 2022).

[2] See: https://policy.trade.ec.europa.eu/help-exporters-and-importers/exporting-dual-use-goods_en (last retrieved: August 7, 2022).

Military cooptation	Synthetic biology, AI, neurotechnology

Mind the (regulatory) gap

Transferring methods such as ubiquitous sensing and control from production and supply chains to human bodies and brains raises fundamental concerns. It can seriously undermine the dignity of humans and their ability to take self-determined decisions that fit their lives and local circumstances. It may also fundamentally change societies, cultures, and what it means to be human. Continuous monitoring and research are needed to assess whether and when the benefits of converging technologies outweight their shortcomings.

We argue that in the light of its socio-technical novelty, cross-domain nature and disruptive potential, converging technologies need international regulation. Current legal frameworks are insufficiently equipped to address these challenges for three main reasons.

The first reason is the limited bandwidth and purview of technology policies, most of which are either domain-specific (e.g. the medical device regulation) or technology-specific (e.g. the recently drafted EU AI Act). However, as we mentioned above, converging technologies are inherently cross-domain and technologically hybrid as they bring together multiple technological systems to produce complex functionalities and systems that interfere with multiple domains of human activity. Domain specific regulations are likely to become ineffective in the light of the cross-domain nature of nanotechnologies.

The second shortcoming pertains to the fact that today's *de jure* risk categories are often insufficiently comprehensive to address the emerging risks of converging technologies. Nanotechnology offers an interesting example. Due to concerns about toxicity [7, 29], i.e. their potential to *cause* diseases, nanomaterials are now mostly tested for *chemical* incompatibility with organic matter. However, there are insufficient risk assessment standards concerning possible aggregation effects or long-term interaction effects of nanotechnology with radiation, despite the fact that this is the underlying functional principle of the Internet of Things and the Internet of Bodies. Similarly, neurotechnologies are evaluated for their safety in terms of biomedical risks (e.g. risk of post-implant brain infection), but not for possible unintended impacts on subjective experience and personal identity (a problem increasingly referred to as mental integrity).

Non-binding frameworks such as ethical guidelines and the principles of responsible engineering and value-sensitive design [30] may offer a more comprehensive approach and guidance. However, it is unclear if they would have sufficient normative power.

The third reason is that existing or emerging legally-binding governance frameworks operate either at the national level (such as the Chilean Neuroprotecion Bill)[31] or a supra-national level (e.g. the European Commission's AI Act)[32]. However, they lack truly international and global governance.

Closing the regulatory gap

Despite the challenges above, we argue that an evolutionary interpretation and expansion of some existing legal and ethical provisions may lay the foundations of an international governance framework for converging technologies.

In particular, we urge policy-makers to fill the afore-described regulatory gaps by generalizing or expanding the purview and scope of currently established, international principles:

First, from the point of view of the Planetary Health Agenda and the Sustainable Development Goals (particularly goal 3 on health), we call for a broader definition of toxicity vs. bio-compatibility as to include also possible interaction effects, such as those involving radiation. Furthermore, the implementation of nanotechnology in bodies should be reversible and, hence, nanoparticles should be bio-degradable within a reasonable period of time, not just bio-compatible. Further requirements are implied by the UN Charter of Universal Human Rights.

Second, the use of converging technologies should always be inspected for possible violations of the Biological and Chemical Weapons Conventions.

Third, the Geneva Weapons Convention, whose Protocols I and IV are aiming to protect, respectively, against non-detectable fragments and laser weapons [g], call for enhanced scrutiny regarding nanomaterials and optogenetics.

Fourth, the principles of cybersecurity and security of critical infrastructures should be transferred from the hacking of devices to the hacking of bodies as to protect against the unauthorized interference with functions of the body and mind. Such interferences should be punishable in a manner that is even greater compared to the hacking of cyber-infrastructures and violating principles of fully informed and free consent.

Fifth, from an Intellectual Property Rights (IPR) perspective, digital twins should be handled at least in accordance with the right to protect one's image [w]. The security and IPR issues mentioned above call for the development of platforms supporting true informational self-determination, i.e., platforms that allow everyone to determine the rules that specify what kinds of personal data may be used by what categories of data users for what kinds of purposes.

Sixth, we call for the development of a new ethical framework for the whole body-mind-machine continuum. This framework should be multimodal (e.g. capable of operating in many modes of activity or occurrence) and multi-scalar (e.g. operating at multiple scales, from the nano- all the way to the macro-level). This framework should be largely based on fundamental ethical codes such as the Nurnberg Code and the Helsinki Declaration. In particular, the Nurnberg Code's pronounced focus on voluntary consent and respect for the person offer a solid ethical basis, from which novel ethical principles can be derived.

Seventh, the protection of personal integrity and privacy should be also guaranteed in the ever-evolving technological scenario of converging technologies. Emerging privacy threats such as mental privacy and reproductive privacy must be overcome. Applications of converging technologies for the purposes of mental influence and behavioral control pose a high risk of violating personal freedoms and rights. Whenever existing normative provisions are insufficient to mitigate these risks, the introduction of neurorights[33-35] such as the rights to mental integrity and mental privacy should be pursued.

Eighth, governance approaches and regulations should appropriately consider currently under-represented groups and focus on protecting vulnerable people, i.e., they should pay particular attention to the most vulnerable and the most affected. A particular role and weight should be given to them in any relevant decisions taken, also with regard to governance, design, and operation of converging technologies.

Nineth, further elements of an effective and acceptable international solution should be determined based on transparent, fact-based, public debates and forms of participatory decision-making that people find legitimate. Finally, to prevent abuse, future regulations should be inclusive, hence participatory, and trustworthy, hence, transparent. Among others, this requires developers to explicitly list and label micro- and nano-scale components, ensure a reasonable degree of explainability and amenability to both ex ante and post hoc inspection for intelligent algorithms[36]. The goal must be to inform people adequately, comprehensively, and truthfully about the nature and amount of the data collected, as well as about the data governance and business models employed.

A final procedural challenge concerns the suitable institutional body responsible for deliberating on the afore-listed reforms and enacting them. We posit that none of the currently existing economic and political systems, institutions and frameworks appears to be well enough positioned to handle the threats in a way that we could fully trust. However, trust is needed, because, if convergent technologies were misused, this would irreversibly damage trust in technological progress altogether. In the socio-technical systems of today, social, not just technical, innovation is needed for a suitable governance framework. Without concurrent social and economic reforms we will not be able to unleash the full potential of converging technologies– in contrast, we will increase the risk of backlash. This calls for novel institutions and a new social contract.

Conclusion

In summary, converging technologies inaugurate a new phase of socio-bio-technical innovation, one in which organisms and machines may converge and co-evolve into increasingly integrated cyberbiological systems. While this phase of technological evolution promises to increase human wellbeing, it also raises substantive ethical, legal, and, in many respects, existential challenges. In this paper, we therefore call for the development of an adaptive and international governance framework, which involves the development of adaptive and evidence-based regulatory mechanisms to coordinate technology management regimes in the face of the complexity and uncertainty associated with technological convergence.

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